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## Zero energy for the Cyprus house

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# **ZERO ENERGY FOR THE CYPRUS HOUSE**

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**A thesis submitted in partial fulfilment of the requirements of  
the Open University for the degree of Doctor of Philosophy**

**Energy Studies - Graduate School  
The Architectural Association London**

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**Collaborating Establishment:**

**Higher Technical Institute, Nicosia,  
CYPRUS**



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## **ABSTRACT**

The thesis aims at the optimization of the regulatory systems inherent in domestic architecture through choice of orientation, building materials and the use of natural resources of energy, to achieve comfort conditions without the need for mechanical heating and cooling for the Cypriot climate.

The thesis is classified in six chapters as follows:

### **CHAPTER 1**

In this chapter, analysis of the energy situation in Cyprus to investigate the potential for energy saving in houses and the possible environmental improvement is carried out.

For this, existing and newly built houses are evaluated to identify deficiencies in the regulatory systems inherent in the built form that result in heating and cooling demands.

### **CHAPTER 2**

The prevailing climatic conditions in Cyprus are analyzed, in this chapter, to assess how energy demands for heating and cooling arise in domestic buildings and to evaluate the free energy systems available to contribute to these requirements.

Moreover in this chapter standards of comfort for single family detached houses in Cyprus are established, through investigation of current thermostat settings and reviews of thermal comfort studies, so that they may be taken as a basis in the optimization study.

### **CHAPTER 3**

This chapter deals with the optimization of a specific house type, to be designed in an ideal environment, to the point of zero fuel consumption for heating and cooling with the aid of microcomputer programmes for thermal analysis. Initially simplified thermal calculations are carried out by using "**Method 5000**", a well established method adopted by the Commission of the European Community Handbook. These are followed by detailed hourly simulations of selected variants using dynamic simulation model **SERIRES**.

### **CHAPTER 4**

This chapter also makes use of thermal calculations as chapter 3, and concludes to comparative assessment of results obtained under chapter 3, and design recommendations for new houses through economic analysis of the varied design measures. From those the profile of the "**Zero Energy House for Cyprus**" is outlined.



## **CHAPTER 5**

The study in this chapter identifies the occupants' factors that influence the efficiency of building performance and the thermal environmental conditions of the **"Zero Energy House"**. It analyses the intervention of the occupants in the design, which is reflected in the variable of fenestration. The analysis is carried out interdependently, in various combinations of shading and ventilation profiles, in computer simulations using thermal analysis programme **"AGRI"**.

A case-study further investigates the thermal effects of the user interaction with the building and confirms the validity of the simulation results. The proposed strategies, at the end of the chapter, aim at reducing the operational counter-effects on the building design.

## **CHAPTER 6**

The conclusions are outlined in the form of criteria for the selection of different design alternatives. These are based on flexibility, operational ease, potential thermal efficiency and elimination of constraints for securing optimal performance for **"Zero Energy Houses"** for Cyprus.



## INTRODUCTION

Cyprus is a Mediterranean island which relies entirely on expensive imported fuel supplies, converting and distributing them to its various sectors of consumption.

The struggle of the Cypriot Government to minimize its deficits while at the same time encouraging tourism, the islands' major profit-making commodity, demands serious consideration of the use of imported resources.

Rapid urbanization and the inefficient use of building services technology has had catastrophic consequences on the islands' ecology, culture and tradition. The successful implementation of energy conservation policies in other countries, especially the adoption of climatic design measures, is a possible model for the island.

The Mediterranean climate of Cyprus requires both the heating and cooling of buildings to varying degrees. The requirements for cooling are often predominant.

Air conditioning systems are already extensively used in hotels, shops, offices and generally in commercial buildings. In domestic buildings there is a trend towards greater standards of comfort which has led to the increasing adoption of air conditioning systems.

In both the domestic and commercial sectors heating and cooling systems are mostly electrical. Fossil fuel based systems are seldom used.

Currently, 25.5% of the total electric energy consumption is in the domestic sector and 30.4% in the commercial. A high percentage of this is attributed to heating and cooling requirements.

These figures indicate that there is a considerable potential for energy savings in buildings by employing appropriate architectural bioclimatic design strategies and improving the common building construction of loadbearing concrete frame, infilled uninsulated brick walls and concrete flat roofs.



# **CHAPTER 1**

## **GENERAL BACKGROUND**



## **1.0 GENERAL BACKGROUND**

### **1.1 GENERAL**

#### **1.1.1 Main Geographical Features**

Cyprus is an island located in the Eastern Mediterranean sea, at 35 degrees North (See Map 2.1) and has an area of 9,251 sq.Km. It is the third largest island in the Mediterranean after Sicily and Sardinia.

Its main topographical features are the two mountain ranges. The massif of Olympus rising to 1951 meters in the centre of the island, and the narrow range of Pentadaktylos of 1000 meters height running along the North-East leaving the broad fertile plain in between.

These features play an important role in its intense Mediterranean climate, characterised by typical seasonal rhythm in respect of temperature, rainfall and weather in general (2.1"Climatic Conditions").

#### **1.1.2 Historical Points**

Cyprus played significant role in the history of East Mediterranean. The most important reason for its progress from the early years (2000 B.C) is the establishment of "kingdoms" in Cyprus during the Minoan period. During that time the Greek language as well as the Greek Gods and way of life were brought into the island.

Cyprus was famous from ancient times because of its minerals, plentiful and good quality copper and timber. For this reason it was claimed by the various great powers (Assyrians, Egyptians, Persians).

During the period of the Empire of Alexander the Great the island was liberated from the Persians and the Ptolemeus became the rulers.

During the Sovereignty of Romans (395 AD) Cyprus became part of the Byzantine Empire. From then on, it had a similar fate as that of the mainland Greece, before it eventually passed into the hands of crusaders and Richard the Lionheart.

The last Crusaders left the island in 1571 when the Turks occupied and kept it till 1878 when Cyprus was delivered to the British. In 1960 it gained its independence and since then it is established as "The Republic of Cyprus". In 1974 the Turkish forces invaded the island occupying its 40% and leaving a pending political problem.



### **1.1.3 Population**

In 1987, the population of the island's Government controlled areas was 556,000 Greeks of which 336,000 were living in urban and 201,000 in rural areas. The refugees amount to 200,000 of which 160,000 are housed by the government.

The Turkish Cypriot population is in addition to these figures but cannot be determined by census as the majority of them are residing in areas occupied by the Turkish Invasion Forces.

### **1.1.4 National Economy**

The economy of the island is flourishing offering fairly high Gross National Product, comparing very favourably with other countries of the region and other developing countries.

The island displayed a miraculous economic recovery from the adverse impact on the growth of its economy in 1974, when the Turkish Invasion caused the uprooting of 1/3 of the population and the loss of the most substantial of the islands resources, tourist and other installations. Since then the upward trend in its overall economic activity continues.

A mainly agricultural country in the past, unpredictable and adverse weather conditions coupled with urbanization tendencies and consequences hit agriculture, and although it continues to provide its fair share in exports, the leading role in the economy is held by the strong growth of tourism, the highest profit making commodity of the island. Expansion of light industry with manufacturing exports fostered by the continued increase in foreign demand, also has an impact on the economy.

From the other sectors, construction trades and services increased their shares in the economically active population at the expense of agriculture and mining.

The island's mining reputation of Homeric years is lost. After the loss of one of the main mining areas in 1974 followed by the gradual depletion of the known economically exploitable ores, and the sluggish foreign demand for minerals, especially asbestos resulted in the decline of the mining sector.



## **1.2 THE ENERGY SECTOR**

### **1.2.1 The General Energy Scene**

The Energy Scene in Cyprus is underlined primarily by the increasing energy demands for economic development accompanied by the rising standard of living and the absence of domestic energy resources with an almost total dependence on imported fuel supplies and an increasing burden on the national economy.

The rate and form of growth in the island result in the uprising trend of energy consumption; Cyprus is a developing country with need mainly for industrialised development presenting an increasing energy consumption at a faster pace than production. This represents an annual rate of growth of 5.1%.

Domestic energy resources such as solar (water heaters), wood (for cooking including charcoal and cooking in the mountainous regions), wind energy (utilised in windmills), are estimated to contribute the 4.5% of the total energy consumption. The remaining 95% consisting mainly of crude oil and oil products is supplied by imports.

Coal is also supplied in limited quantities after a partial switch over in 1984 has been made in the factories of the cement works, major energy consumer of the industry. This switch over to coal, offers better economic terms, diversification from exclusive reliance on oil products and a prospect of a coal fired power station to be operated in the near future.

The demand for energy in Cyprus does not justify either the import of natural gas nor the construction of a nuclear power plant.

The annual figures of the imported forms of energy are about 0.6 million metric tons of crude oil, processed in the national refinery, 0.6 million tons of oil products and 0.1 million tons of coal, giving the total annual (1987) energy consumption of 1.277 million tons of oil equivalent (Toe). This with a population of 556,000 corresponds to a 2,15 Toe per capital annual consumption; a figure comparable to that of other Mediterranean countries but lower than the EEC countries.

### **1.2.2 Energy Consumption by Sector**

A breakdown of energy consumption by sector is given in table 1.2.1.

From the table it is observed that the domestic sector holds the 10% mainly used by households appliances and a small but growing part by heating and cooling in the building.



Transport is the largest energy consuming sector (33.2%). This is attributed to the islands rapid growth of tourism and the development of its associated sectors of aviation and marine.

The industrial sector follows with a share of 25%; the two cement and eight brick factories are its main bulky consumers while the rest of the consumption is distributed amongst the other industrial plants operating in Cyprus and classified as low energy plants.

In terms of end-uses, energy is offered in the form of fuel oil, electricity and solar energy. The largest consumption of fuel oil amounting to 40%, is absorbed by industry sided by transport with the same percentage. The domestic and agricultural sectors follow with 10% each.

As far as electricity is concerned the primary consumers are the domestic and commercial sectors, having an equal share of 60% of the total. Industry follows with 31%, agriculture with 6%, while transport's consumption of electricity is negligent. A more detailed breakdown does not exist but a high percentage of this is attributed to domestic and commercial heating and cooling.

The latest statistics of 1988 present a 13.0% increase of electricity consumption over the previous year mainly recorded by the households, manufacturing enterprises and hotels. Solar energy is utilized entirely in the domestic and commercial sectors.



**Table 1.2.1 Sectorwise Annual Consumption of Energy in Cyprus**

Sector	% Annual Consumption	
	Electricity	Total (Electricity included)
Domestic	21.3	10.0
Industry	20.4	25.0
Restaurants/Hotels	7.1	4.5
Agriculture	3.3	9.4
Wholesale & Retail Trade	3.3	4.0
Transport	2.3	33.2
Services	1.2	2.0
Other Sectors	17.5	6.2
Unbilled* Consumption	23.6	5.7
<i>* Represents the consumption made in the area under the Turkish Invasion Force, the proceeds of which are presently unrecoverable.</i>		



### 1.2.3 Electricity

The electric power system consists entirely of thermal power units. The installed capacity is 536 MW and the peak demand is in the region of 300 MW.

Two 60 MW oil fired units are in full commercial operation since 1989. Electricity production accounts for 33% of the total energy requirements of the island.

The efficiency of production of electricity from oil is 0.27 toe/1000kwh, rather low compared to the international values of 0.22 to 0.23 toe/1000 kwh. This is mainly due to the size of the system, its installed capacity and the load demand duration curve.

### 1.2.4 Energy Planning and Policies

In the development of Cyprus, energy was not a major issue until 1973. However a number of factors such as:

- Energy price increases,
- Rising demand for energy that followed,
- Absence of known commercially exploitable conventional energy resources and therefore the almost total dependence on imported energy,

emphasized the vital importance of energy to the island's economy and urged the need for energy planning.

After 1973, the immediate energy problem and the long time required for development of limited potential of renewable sources of energy in Cyprus (Solar, wind and biomass) necessitated emphasis on energy conservation. Nevertheless in parallel, and in recognition of the growing importance of energy in the projected future, the government increased efforts towards the establishment of a comprehensive long term energy policy. In this context the government with the assistance of UNDP (United Nations Development Project) undertook the project for "Energy Conservation and Development". The main aims of the project which lasted for four years were to :

- a) Establish an overall energy development policy for Cyprus.
- b) Reduce the country's requirements for imported energy through energy conservation.
- c) Develop non-conventional energy resources.
- d) Establish an institutional framework for energy development and planning in Cyprus.

This project was followed up by "The comprehensive Energy and Conservation Project" undertaken by the government with the assistance of the World Bank. The study was completed in 1985 providing the government with:



- a) Detailed, realistic 5-year plan.
- b) The parameters to be considered for a 20-year energy plan with projected scenarios for demand and supply.
- c) Capability of handling regular systematic and dynamic, short, medium and long range energy planning procedures within the government.

Recommendations from energy consultants for regular updating of the study to account for the country's energy sector changes, urged the government to acquire energy models for its planning procedures.

These are computerised programmes extensively used for the preparation of energy planning studies in Cyprus mainly:

- (i) To update the country's energy requirements based on selected economic scenarios and
- (ii) To evaluate the impact of proposed energy conservation measures and development of renewable sources of energy.

The studies address large number of factors and parameters which include micro-economic data, special variables, energy conservation policies, pricing procedures and environmental issues.

Besides the local considerations, awareness of the international energy scene, exchange of information, and cooperation with all countries of the region, are also beneficial, since changes and the existence of oil and coal in them directly affect the island's energy planning.

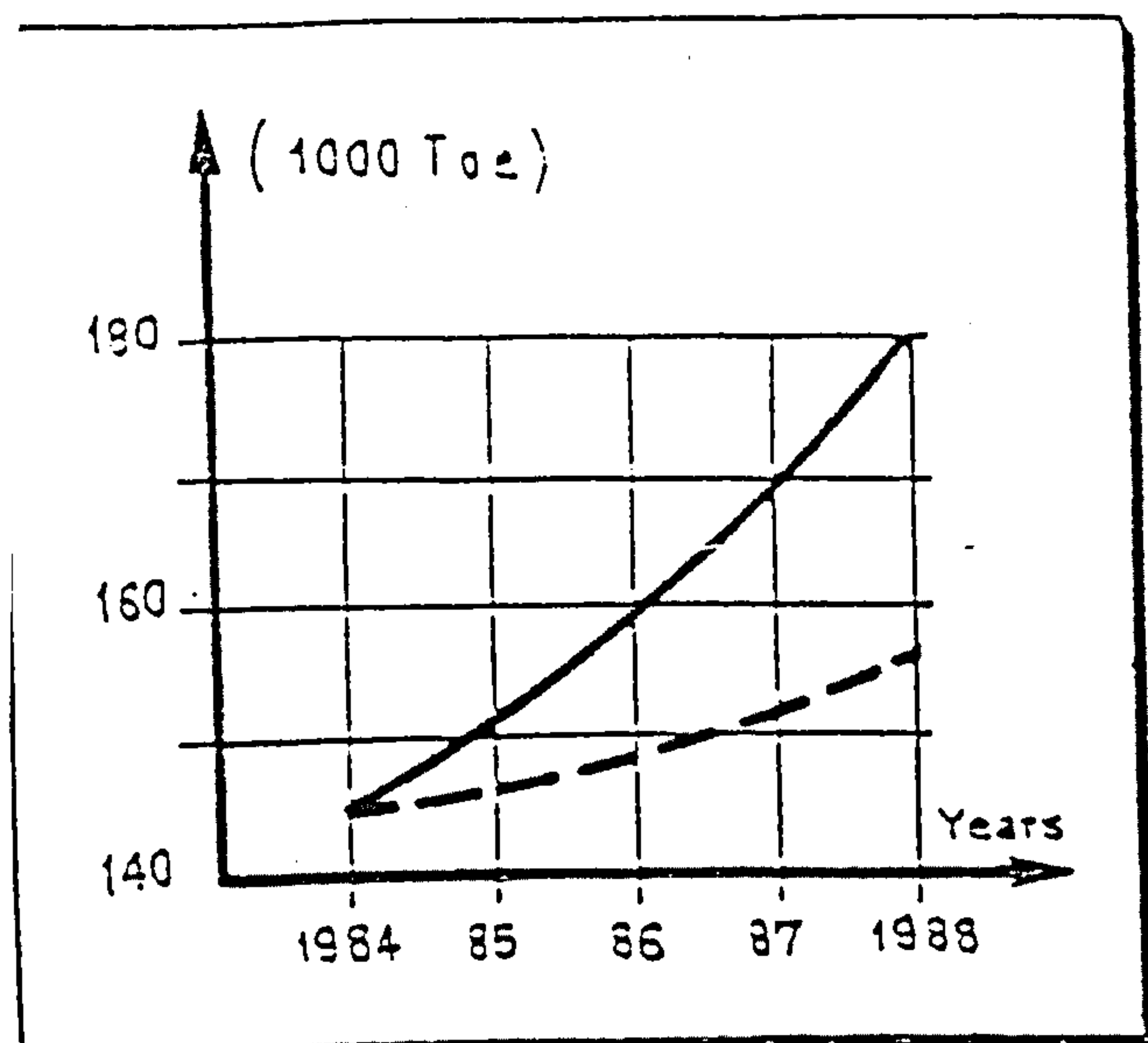
Presently, due to the current low prices, the lengthy and costly utilization and production of energy from natural resources, the government's energy policies are mainly aiming at energy saving, especially in view of the wide margins existing in all its sectors of economy.

Within this framework and in further anticipation of the consultants' priority\* to dwellings (See graphs 1.1), as explained in the introduction, this study is focusing on energy conservation in houses.

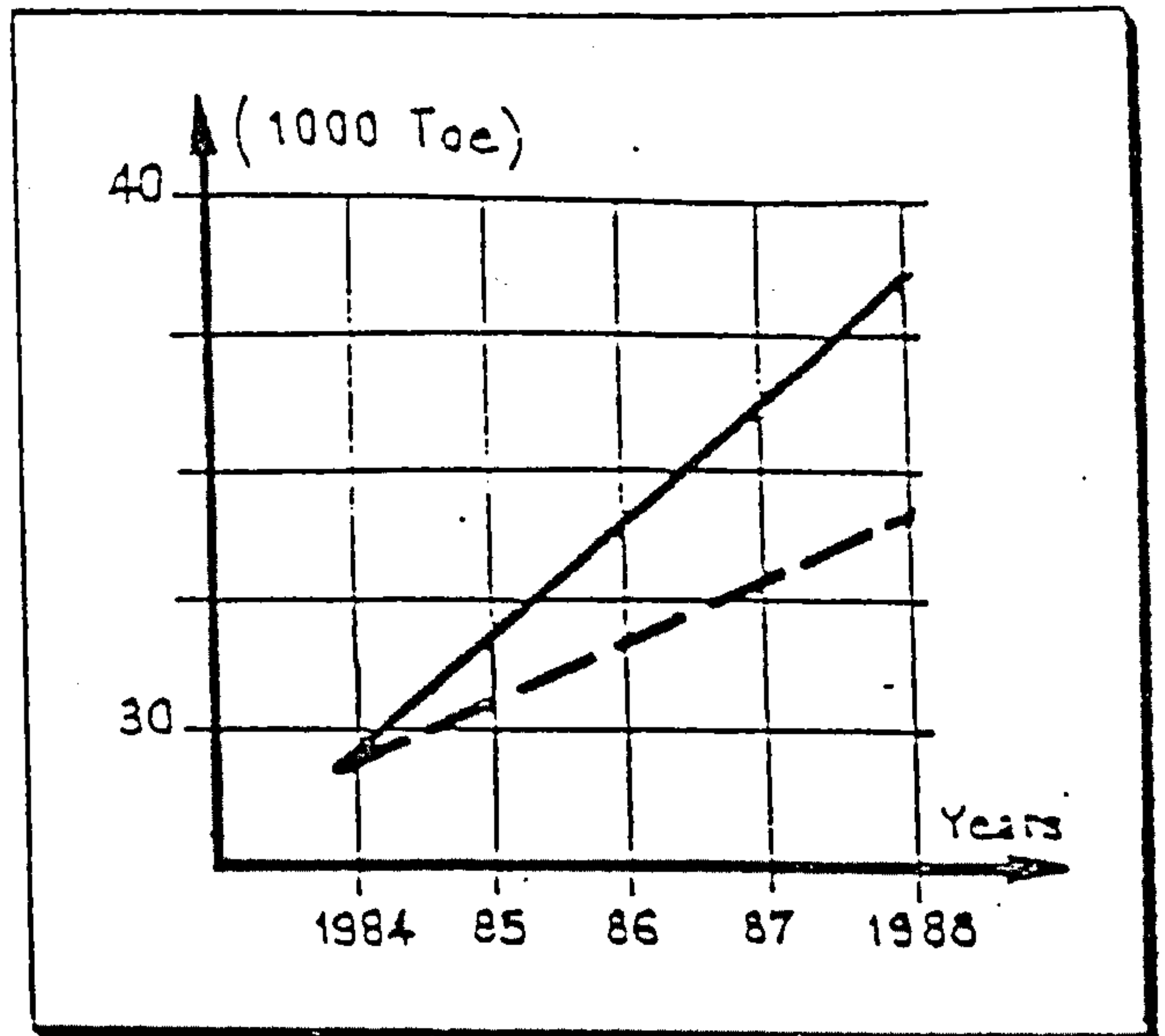
*\*The consultant's priority is based on estimated savings from dwellings contributing to 75% of the expected total of 70,000 Toe from both Domestic and Commercial sectors over a 5-year period.*



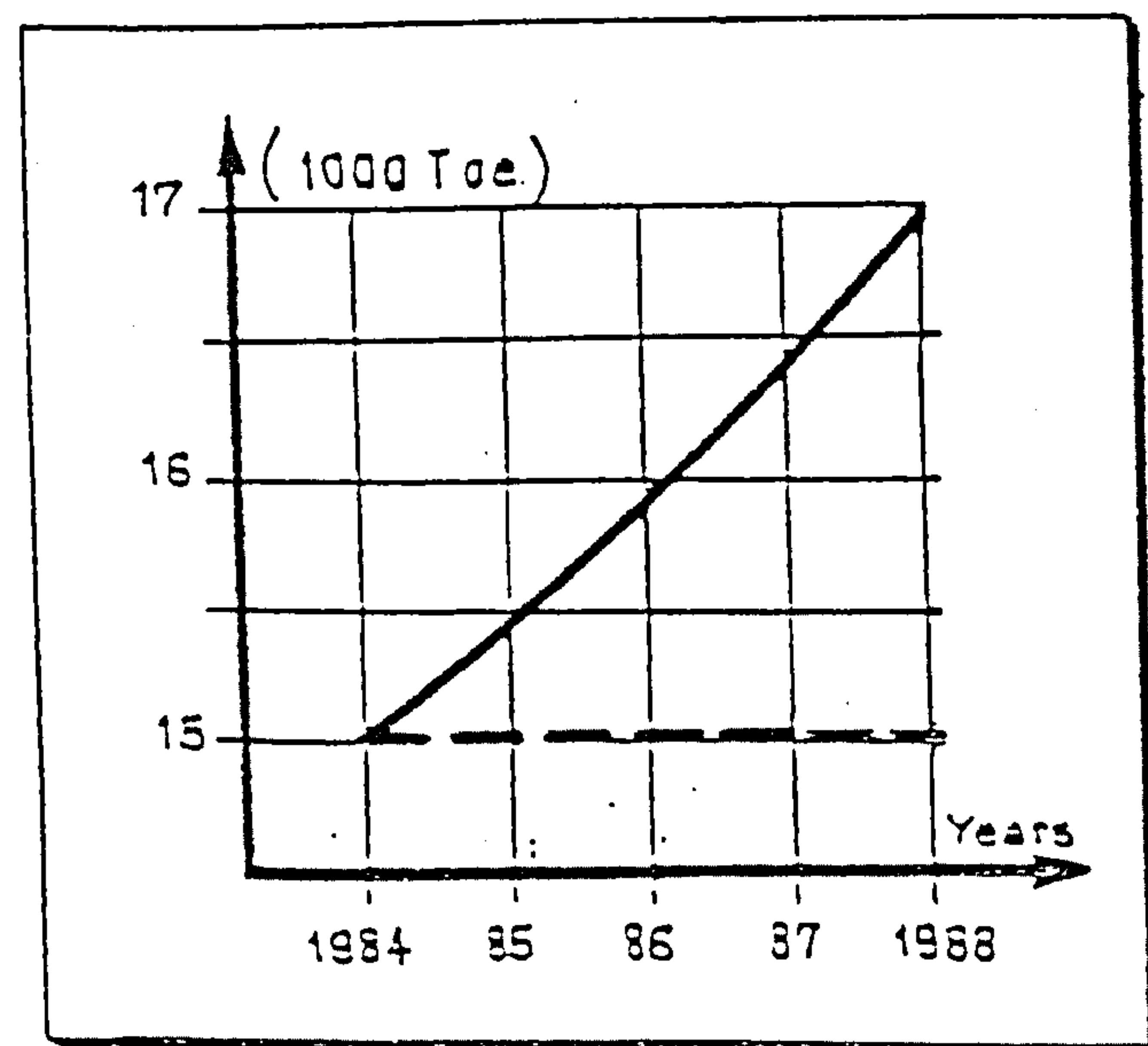
# ENERGY SAVINGS IN THE FOUR TARGET SUBSECTORS



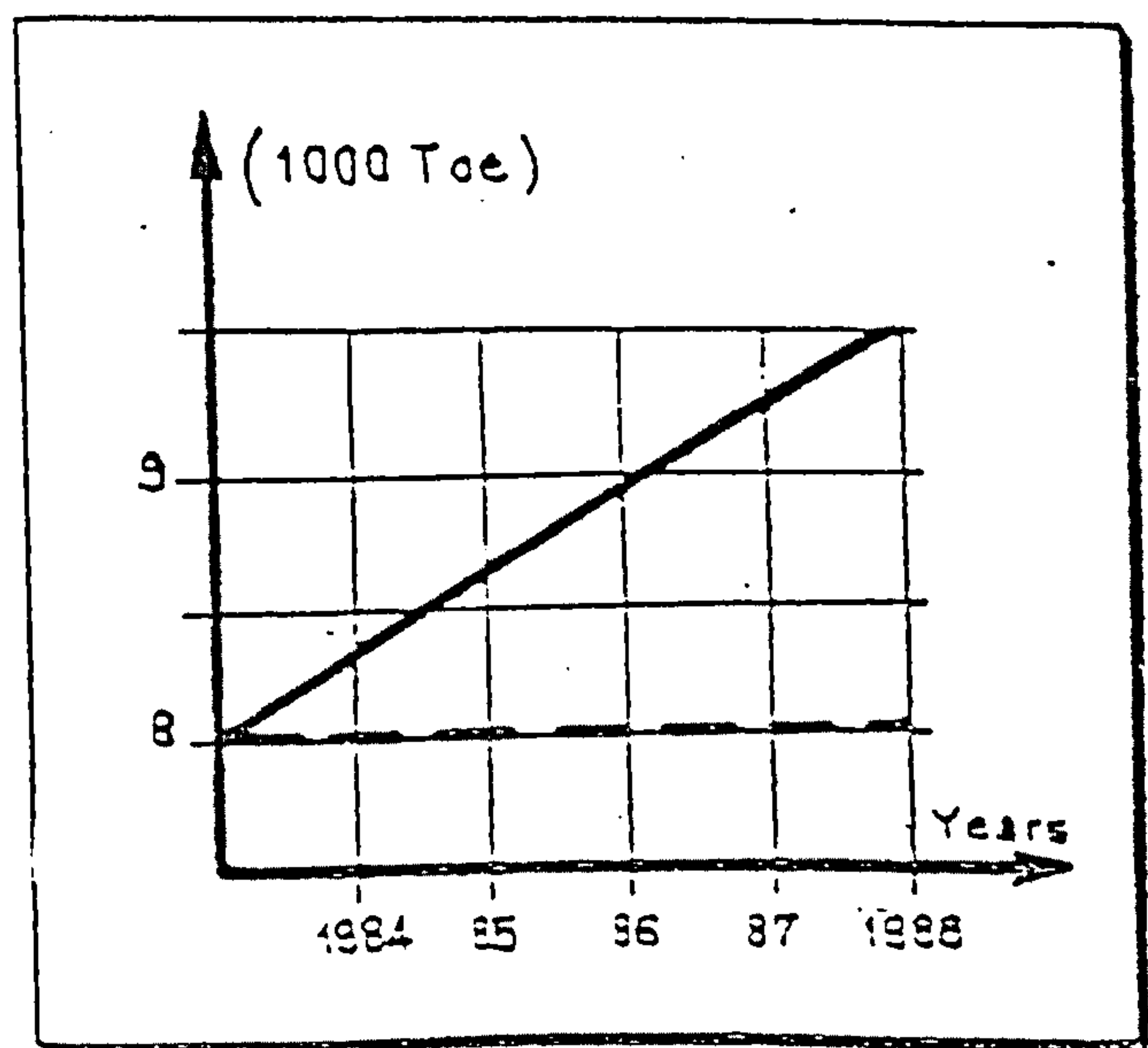
DWELLINGS



HOTELS, OFFICES



GOVERNMENT



LOCAL COMMUNITIES

— Current trend scenario  
 --- Energy Master Plan scenario

GRAPH 1.1



### 1.3 ENERGY SOURCES AND USAGE IN HOUSES

#### 1.3.1 Energy Consumption In Domestic Sector

The total annual (1987) energy consumption (electricity included) by the domestic sector in Cyprus comprises 10.0% with electricity at 21.3%. (See table 1.2.1 for other sectors).

Based on Consumption by Households (*Table 1.3.1*) a rate of growth of 5.5 is indicated between 1984 and 1988.

**Table 1.3.1: Energy Consumption by Households**

Primary Energy Consumption (1,000 t.o.e)		
1982 144	1984 145	1988 180

*Source: Consultant estimates (Ref: 1.10)*

Break-down of residential energy consumption (1984) in terms of type of final energy used (*Table 1.3.2*) shows its large share of electricity consumption.

**Table 1.3.2: Final Energy Used by Households**

Electricity	L.P.G.	Solar	Kerosene	Diesel fuel	Wood
50%	18%	24%	3%	3%	2%

In terms of end-use of energy in households (*Table 1.3.3*), Water heating holds the highest place being half total consumption, and more than half of electricity. This is followed by heating with a national average consumption of 0.25 t.o.e./household.

**Table 1.3.3: End Uses of Energy in Households**

W. Heating	Heating	Lighting	Cooking	Electric appl
54%	23%	13%	6%	4%



**Table 1.3.4: In terms of heating systems in households**

C. Heating	L.P.G.	Electricity	Kerosene	Wood
10%	64%	10%	10%	6%

### **1.3.2 The Residents Aspect on Energy**

#### **1.3.2.1 Financial Concern**

From a survey, carried out in Cyprus (*Ref:1.10*), it was found that all families interviewed attribute a great part of their budget to energy expenses.

About 2/3 have the impression that these expenses amount to more than 15% of their budget; this is an exaggerated estimate of energy expenses, compared to the actual figures (*Ref:1.12*) which indicate an 8% average percentage.

#### **1.3.2.2 Energy Conservation Awareness**

Although 2/3 of the surveyed households claim that when using their equipment they consider energy conservation, nevertheless when they purchase equipment, energy consumption is rarely considered due to the little information available.

#### **1.3.2.3 Expectations for Public Measures**

Most of the residents (90%) expect public assistance in terms of:

- (a) Information on technical solutions for energy conservation.
- b) Assessment of building equipment and installations.
- c) Financial support for improvements in existing and better standards in new houses.

### **1.3.3 Dwellings and Insulation**

Although, the notion of insulation is still in its infancy, there is nowadays a rising trend in its use. People view the matter with an open mind. More than 40% are prepared to invest up to £1250 on insulation only if they are convinced that its worth it. (*Ref:1.10, 1.14*).



Most of the insulation works are carried out on urban, private houses. In rural areas insulation works are very rare. This is mainly due to lack of information, money and priority of its expenditure.

### 1.3.4 Dwellings and Space Heating

Space heating in dwellings, as can be seen from table 1.3.4, is mostly based on Liquid Petroleum Gas covering two thirds of the present household space heating equipment.

Comparing present household heating systems and house-holders intentions in purchasing future ones (Ref: 1.10, 1.12) it is anticipated that gas is to lose its supremacy in the future and fall to one third of the present market. (Table 1.3.5)

**Table 1.3.5: Current heating systems and future trends**

Current Main heating system:		Gas	Elect.	C.h	Keros	Wood	Future % break-down
		62	12	11	9	6	
Residents proposals for future systems	Gas	26	1	---	1	4	32
	Electric	5	5	---	1	---	11
	C. Heating	15	5	10	---	1	31
	Kerosene	1	---	---	7	---	8
	Wood	10	---	1	---	1	12
	Solar	4	---	---	---	---	4
	No answer	1	1	---	---	---	2

*Source: Survey on Household Energy Use (Ref: 1.10, 1.12)*

From the above table, Central Heating equipment presents the most interesting information, tending to increase from 10% to 30% of the markets heating installations.

There is no significant trend towards electrical systems, the percentage of which will remain constant or slightly diminish possibly from 12% to 10%, to give way to heavier systems, such as central heating and more sophisticated heating-cooling systems.

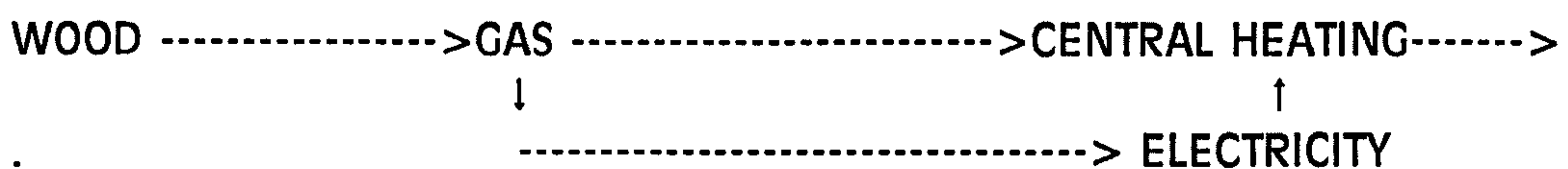
Although electricity is an expensive form of heating, the users criteria of



comfort, seem to outweigh their concern of cost.

As far as wood is concerned, the trend is more complicated; fashion criteria tend to move its rural users to other heating systems, whereas "savings" and romantic or symbolic criteria revert its urban users back to wood.

The general progressive picture appears as a movement from wood and gas to heavier heating systems, with electricity used as a transition phase, and central heating as the ultimate popular option:



### 1.3.5 Cooling Systems

Most households do not have any cooling systems, either because they consider them unnecessary or because they are far too expensive.

There is, however, an apparent tendency towards higher levels of comfort, in private houses, which leads to the trend of incorporating air conditioning systems in them. At present most homes use electrically operated systems.

### 1.3.6 Response to the Dwelling's Thermal Environment

Occupants seem to be as sensitive to cold in winter as to heat in summer; from the people interviewed, (Ref:1.10).

**For the winter,**

- 34% consider their houses really cold
- 50% comfortable in the winter.
- 26% fairly warm

**For the summer,**

- 33.5% consider their houses very hot
- 33% fairly cool



- 33.45% comfortable

The above figures vary according to the type of building and whether they are rural or urban.

Generally the urban dwellers living in private houses have a higher standard of living and attribute more importance to their comfort; less than 10% consider their houses comfortable in winter and 50% consider them too hot in the summer.

This response of the urban dwellers to their households is justified by the rising trend in towns for installations of central heating and cooling systems in houses.

- Urban dwellers living in flats feel more comfortable both in winter and summer; about 80% are satisfied with the thermal Environment of their flats in winter and only 15% consider them too hot in the summer.
- Rural dwellers are far more sensitive to cold in winter, than the urban ones living in private houses, whereas they are less sensitive to heat in the summer.
- Refugees, living in individual houses set-up by the government, have similar response to the comfort of their households as the dwellers of an average private house.
- Nevertheless refugees living in flats are far more dissatisfied from the thermal performance of their dwellings both in winter as well as in the summer.

### **1.3.7 Potential in Dwellings for Energy Saving and Environmental Improvement.**

Based on the consumption of energy by the domestic sector and the consultants estimates (Ref:1.10) for savings (See graph 1.2), there exists enormous potential in saving energy in dwellings. To the total targeted 75,000 t.o.e. savings over a period of five years, from domestic and commercial buildings, the contribution from dwellings is expected to be 35,000 t.o.e.

This expectation is justified considering the lack of insulation, (1.3.3 "Dwellings and Insulation") and the inadequate thermal Environmental conditions in them as perceived by their inhabitants (1.3.6 "Residents Response to the thermal Environment" ). Further to this, present construction trends indicating distinct preference to private detached houses over flats, (table 1.3.6) coupled with higher standard of living and therefore demand of improved comfort conditions in them, (Table 1.3.8) imply larger energy saving potential in this particular type of dwelling.



**Table 1.3.6: Construction Trends**

Housing Units		Stock as of 1.1.1984	Construction 1984-1988
Private Housing	Houses	92,300	11,320
	Flats	51,600	8,240
Refugee Housing	Houses	10,000	6,510
	Flats	15,400	2,870
Total	Houses	102,800	17,830
	Flats	67,000	11,110
<i>In 1986 4,380 houses and 2,120 flats were built. Presently 40% of flats (2,000-2,500) built in 1976-81 are empty.</i>			

**Table 1.3.7: Number of Households**

District	Total	Urban	Rural
Nicosia	46,992	28,484	13,503
Larnaca	19,062	6,736	12,325
Limassol	36,278	24,472	11,786
Famagusta	5,550	-----	5,350
Paphos	12,741	2,655	10,086
Total	120,623	62,367	58,256

*(Statistics 1984)***Table 1.3.8: % of Houses built in 1986 with Central Heating**

Nicosia	Famagusta	Larnaca	Limassol	Paphos
1,530 70%	190 2%	665 6%	1,480 10%	575 6%



**Table 1.3.9: Heating Requirements calculated on the basis of Degree Hours (In kwh/m<sup>2</sup>)**

Nicosia	Larnaca	Limassol	Paphos	Polis
38.9	21	12	10.3	19.4

*Note: The large difference of heating requirements between Nicosia and the other towns is mostly due to the capital's inland location as explained in the "Climatic Conditions in Cyprus" (2.1).*

The sensitivity of urban dwellers to comfort standards (1.3.6 "Residents Response to the Thermal Environment"), the urbanization tendencies and specifically for Nicosia (Table 1.3.6), the most demanding town for heating and cooling, (Table 1.3.9) define it as the location to be given priority for energy conservation.

## **1.4 ENERGY CONSIDERATIONS IN THE CYPRIOT HOUSES**

### **1.4.0 Introduction**

This chapter deals with the evaluation of the building sector in Cyprus. At a broad and general level it describes and investigates the state and use of Cypriot houses. It traces the thread of continuity from the Traditional to the Contemporary house, identifying deficiencies in the regulatory systems inherent in the built form that result in heating and cooling demands. It highlights possible improvements, derives lessons from Cypriot traditional architecture and outlines proposals.

### **1.4.1 Building Regulations and Planning Legislation**

#### **1.4.1.1 Existing Situation**

In Cyprus today there are no standards, codes of practice, or building regulations regarding solar aspects or thermal properties of buildings. The present building regulations concern town planning, siting and layout of buildings, fire safety and to some extent health and structural safety (Ref: 1.18(iii), (iv)).

The main building regulations which may affect the plot and the design of the house, relating to solar aspects, concern distance from boundaries, area of coverage and building height as follows:



- a) **Distance from boundaries:** the building must be set back a minimum distance of 3.0m from all boundaries of the plot. There are two exemptions to this rule concerning verandas and auxiliary buildings, which can abut to the rear of the site boundaries.
- b) **Plot coverage:** For the ground floor of the main building this is a maximum of 50% of the plot area. If there is auxiliary building (garage, store room etc), this becomes 40% and 10% for the auxiliary building.
- c) **Height:** the height of the main building can rise up to three storeys and the auxiliary no more than 3.5m.

Currently in the Ministry of Commerce and Industry there exist a draft of "Standards" concerning, in the main, thermal Insulation of buildings (*Ref:1.20(vi)*). These are based on studies carried out during several visits of UNDP experts to Cyprus and takes into account the actual state of construction on the island, the most commonly used techniques, and building materials (*Ref:1.25*).

#### 1.4.1.2 Considerations for Regulations

Certain rules and regulations must be imposed so that the energy consumption of new buildings can be limited by law.

Methods exist extensively throughout Europe for assessing energy efficiency of buildings. These must be imported, adapted and made known to architects, building designers and appropriate authorities, (*Ref:1.19*) in order to:

- a) Increase the awareness of building designers of the various limitations of location, prices etc., and accordingly, to select appropriate designs and construction methods and materials.
- b) Assist the institutional and financial authorities to built up incentives and regulation policies in order to discourage energy-intensive buildings.

Regulation should take into account energy conservation objectives as well as the minimization of extra cost.

The "standards" being prepared, as above mentioned, should not be used as a basis for regulations (*Ref:1.20(vi)*). Work implemented for the preparation of standards is a very interesting source of information on the present energy efficiency of Cypriot buildings and on the possibilities for improvement.

They offer a useful range of better construction methods for all architects and building designers.

Regulations should, on the other hand, concern the general ratio of energy



needs and internal loss coefficients and would depend upon :

- Type of building (*individual, collective, hotel...*)
- Type of space-heating and cooling system to be installed.
- Possibilities of natural solar gains.
- Climatic zone (mountains, plains...)

This kind of regulation based on a general ratio is to be preferred to imposed "Standards" for each part of construction (walls, roofs, openings etc.,) because:

- It takes into account the variety of situation encountered.
- It imposes an objective, but not the means to achieve it, which leaves architects full freedom to develop their projects.

The authority to implement regulations should be given to district officers in charge of issuing building permits.

This will require:

- The introduction of suitable parameters in the building permit forms, in order to allow officers to assess the energy efficiency of the buildings. (The officers being trained in simplified methods of calculation).
- Or the provision of the energy efficiency coefficient of the proposed buildings by architects , after adequate training.
- Or a combination of the above.

#### **1.4.2 Building Materials in Cyprus**

Although most building materials used in Europe are available on the Cyprus market it is nevertheless important to consider materials that are locally produced and commonly used. Also important is the consideration of availability and production of insulation materials. Most of the information given regarding materials is based on the studies carried out in Cyprus by a United Nations Development Project (UNDP) Heat Insulation Advisor (*Ref:1.25*).

##### **1.4.2.1 Structural materials**

The bricks and concrete blocks used for the building structures are made in Cyprus but no official values of their thermal conductivity are available. The moisture content of materials and its variations (an important factor for the



heat conductivity coefficient of the material and the calculation of thermal transmittance of building components) are taken from countries with climatic conditions similar to those of Cyprus.

#### **1.4.2.2 Insulation materials**

The present market for insulation materials and correspondingly the production of such materials is very limited in Cyprus (*Ref:20(ii)*). Should insulation regulations be introduced to the building industry, on a compulsory basis, then the potential exists for local production of insulation materials in Cyprus. However the extent of insulation materials, for the purpose of this study, is confined mostly to those currently available locally. These can be grouped into four main categories:

- a) Plastic foams**
- b) Mineral wool**
- c) Lightweight concrete**
- d) Organic materials**

In the plastic foam category, expanded polystyrene foam is produced in Cyprus from raw materials; whereas extruded foam and polyurethane foam in the form of slabs are imported into Cyprus. Mineral wool products (glass wool and rockwool) are also imported. The lightweight concrete is used in situ, in concrete slabs and as loose fill in cavities; it is produced from imported expanded raw materials and is rather expensive compared to other materials. In the category of organic insulation materials the most significant one for Cyprus is cork, which was extensively used before plastics became widely available (*Ref:20(ii)*).



### 1.4.3 Architectural Trends and the Bioclimatic Approach

The traditional Cypriot houses, with great wisdom, provided shelter from the extremes of climate in a variety of ways without consuming very much energy. The coolness of old buildings on a hot summer afternoon never fails to impress not only visitors but even the locals and make one wonder how the indigenous builders could create such comfortable buildings without the aid of scientific knowledge.

In these days of fuel shortage it is necessary that our modern buildings also provide this shelter with the least expenditure of energy. There is today a vast accumulation of technical information and yet our present-day houses tend to be less comfortable than traditional ones (*Ref:1.24*).

A retrospective examination of traditional architecture is necessary to determine how our predecessors tackled thermal design problems, both in the context of their life styles and with the tools and techniques available to them (*Ref:1.16, 1.21*). It is also important to understand the differences between the present-day approach and strategies and those of the indigenous builders.

The study in depth of the evolution of vernacular architecture reveals in the form of houses, a complex of cultural values, needs, influences, wishes and dreams, and how they were influenced by the climatic conditions of their locality (*Ref:1.7,1.14, 1.16,1.21*).

#### 1.4.3.1 The Traditional House

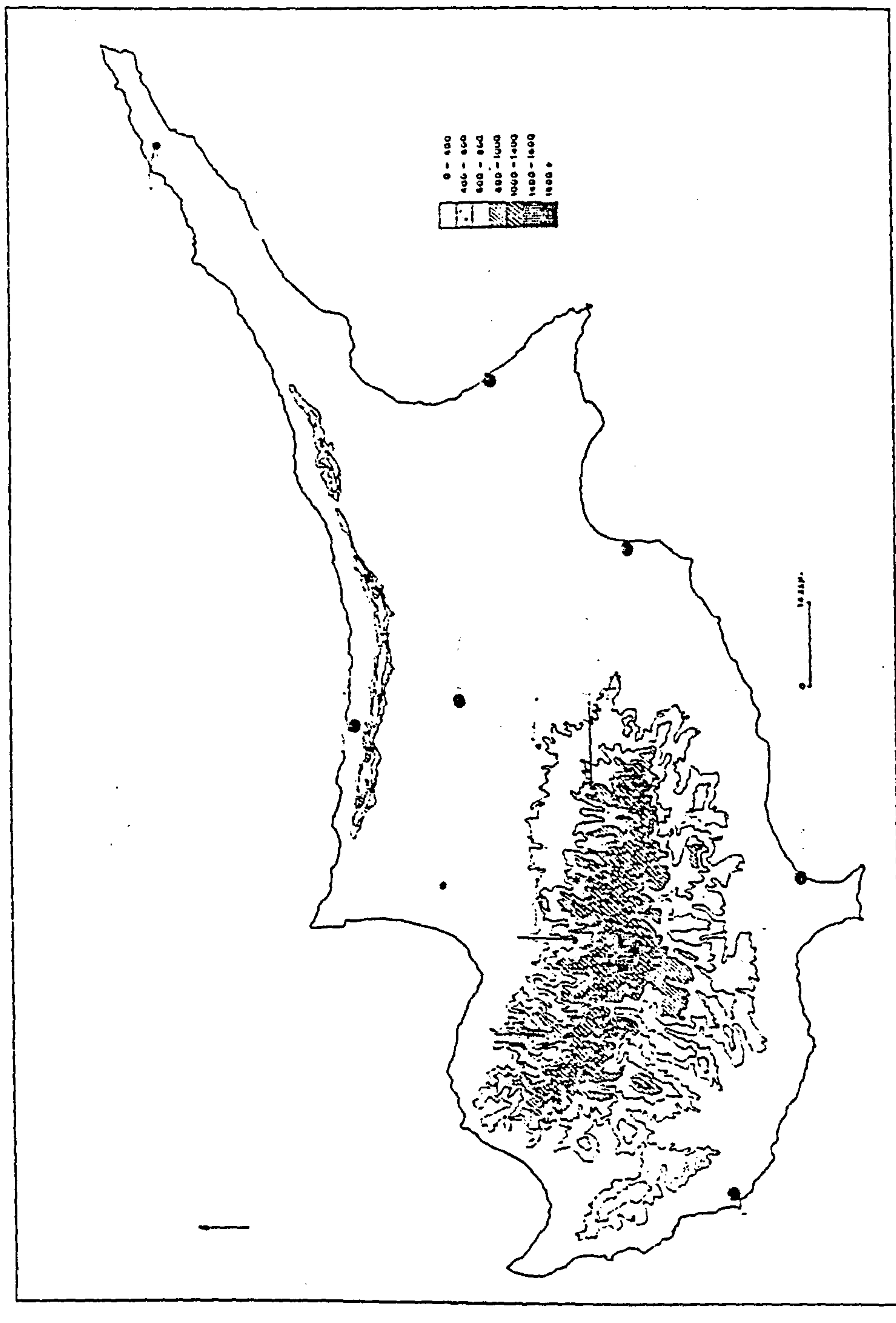
Vernacular Cypriot architecture is difficult to define; like the land from which it springs or grows it reflects the varied life style of its inhabitants and the availability of the resources of each region.

The variety of terrain on the island ( plains, hills, mountains, seashore (*Ref:1.13*)), spawns a variety of needs, building materials and hence building form (*Map:1:1*). In addition, the long experience of local builders and their devotion to tradition, intermingled with the ability to receive and assimilate foreign cultural preferences are reflected in the variety of habitats created on the island (*Ref:1.9*).

#### The Archetype

Tracing the evolution of vernacular Cypriot architecture, an archetypal form of a single, long, rectangular roomed building ("Makrinary"=Long room) is revealed as the simplest basic shelter of the Cypriots, (*Ref:1.16,1.21*).





Map 1.1: Cyprus



The division of this room, ("Dhichoron"=Double-space), the addition of the Portio ("Heliakos"=Solarium), and other rooms plus the courtyard, developed the layout into various configurations which interrelated with a specific lifestyle, needs, climatic conditions and topography (*Fig:1.4.1*).

### **The Solarium**

The Solarium is an indispensable solar feature of the Cypriot house and a unique building element in Greek vernacular architecture (*Ref:1.12*). It is a focal space around which the various activities of all the other spaces are synthesised whether the house is in the plains, in the mountains, the villages or the cities (*Fig:1.4.4*).

The solarium acts as a transit space and unites the outer with the inner building layout (*Fig.1.4.5*). It is a significant architectural feature and an early instinctive approach to passive solar design. It is an extension of the house outwards and simultaneously of the courtyard inwards. An internal space with its south side open accommodates the functions of the "Dhichoron" in the summer and in the sunny winter days. Also the activities of the courtyard are transferred to the solarium when the weather does not allow them to take place in the open air.

Its solar role was predominant whether acting as a portio, as an arcuated corridor, as a central axis or even when it evolved into a self-contained space (*Fig.1.4.4*). It provided the house with its focal space even in periods of prosperity when the construction of bigger multi-roomed houses was financially and technically possible.

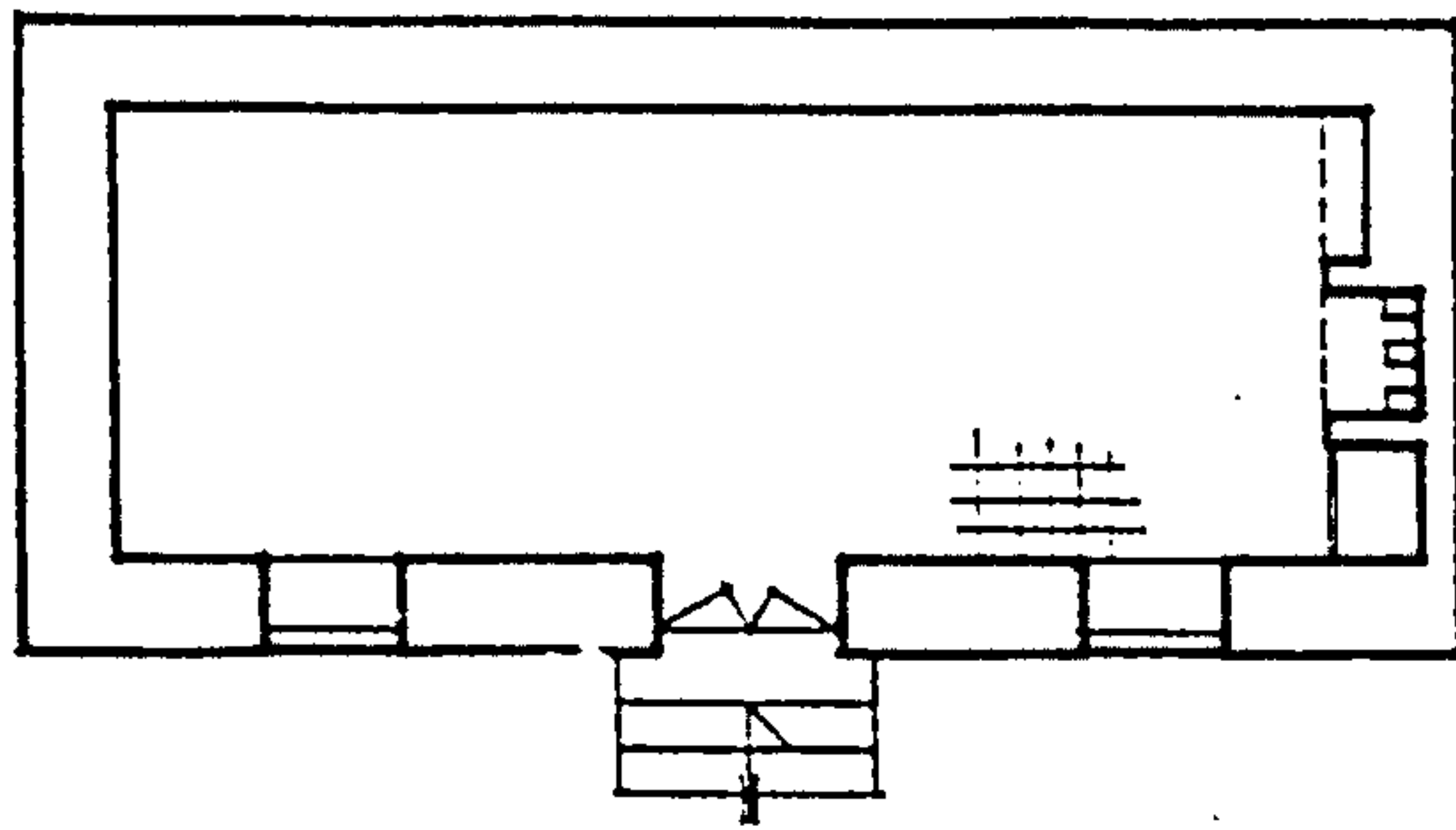
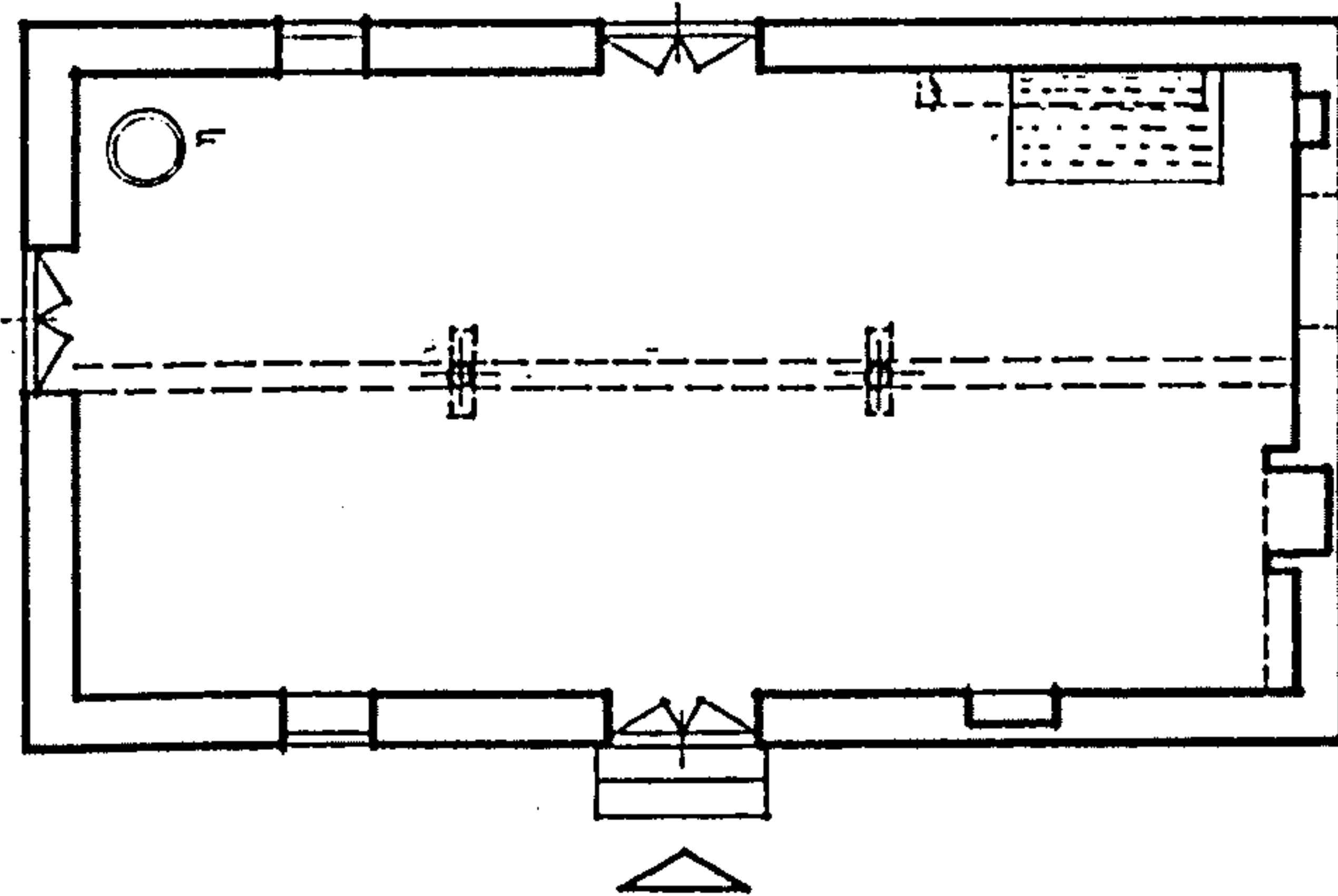
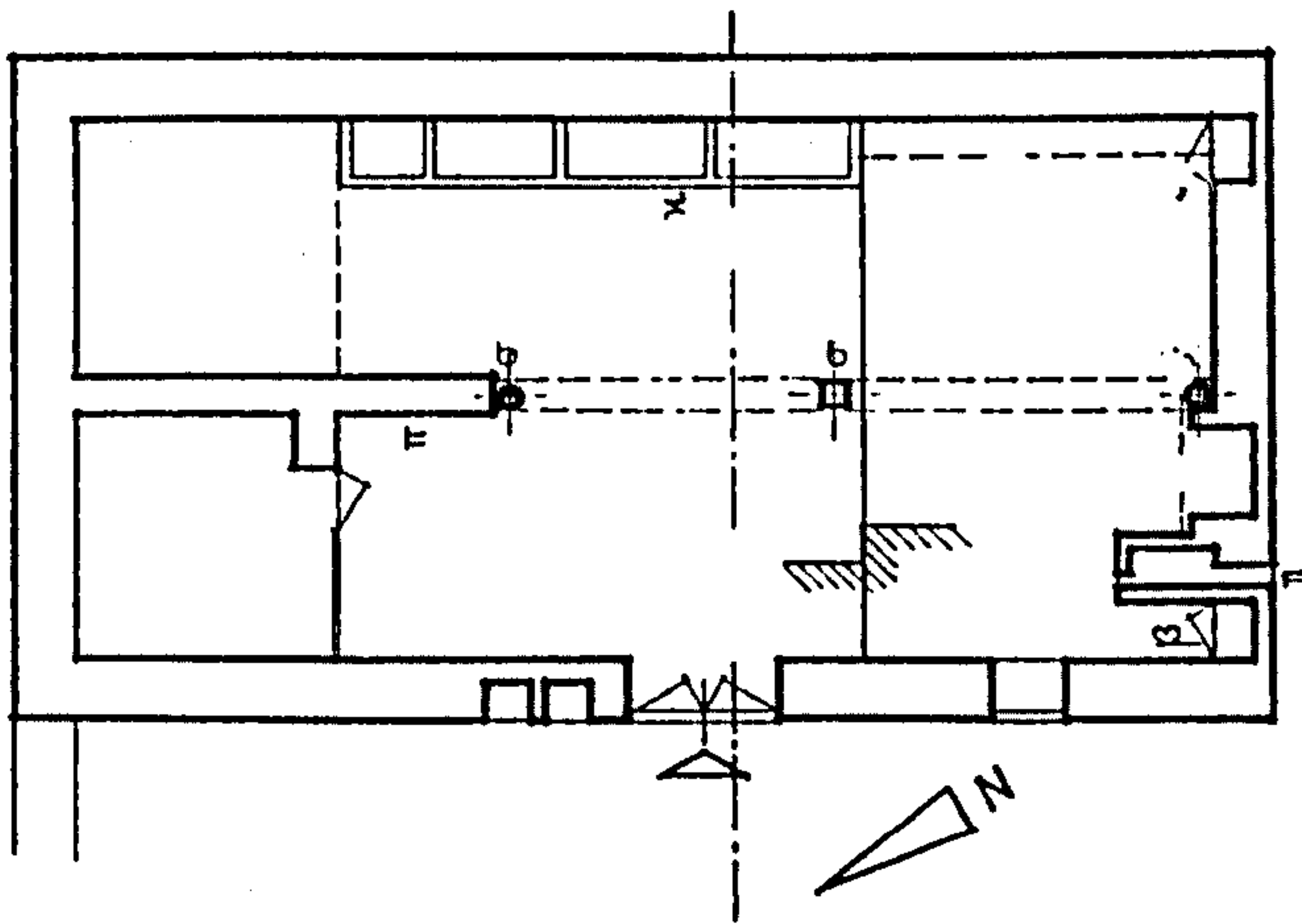
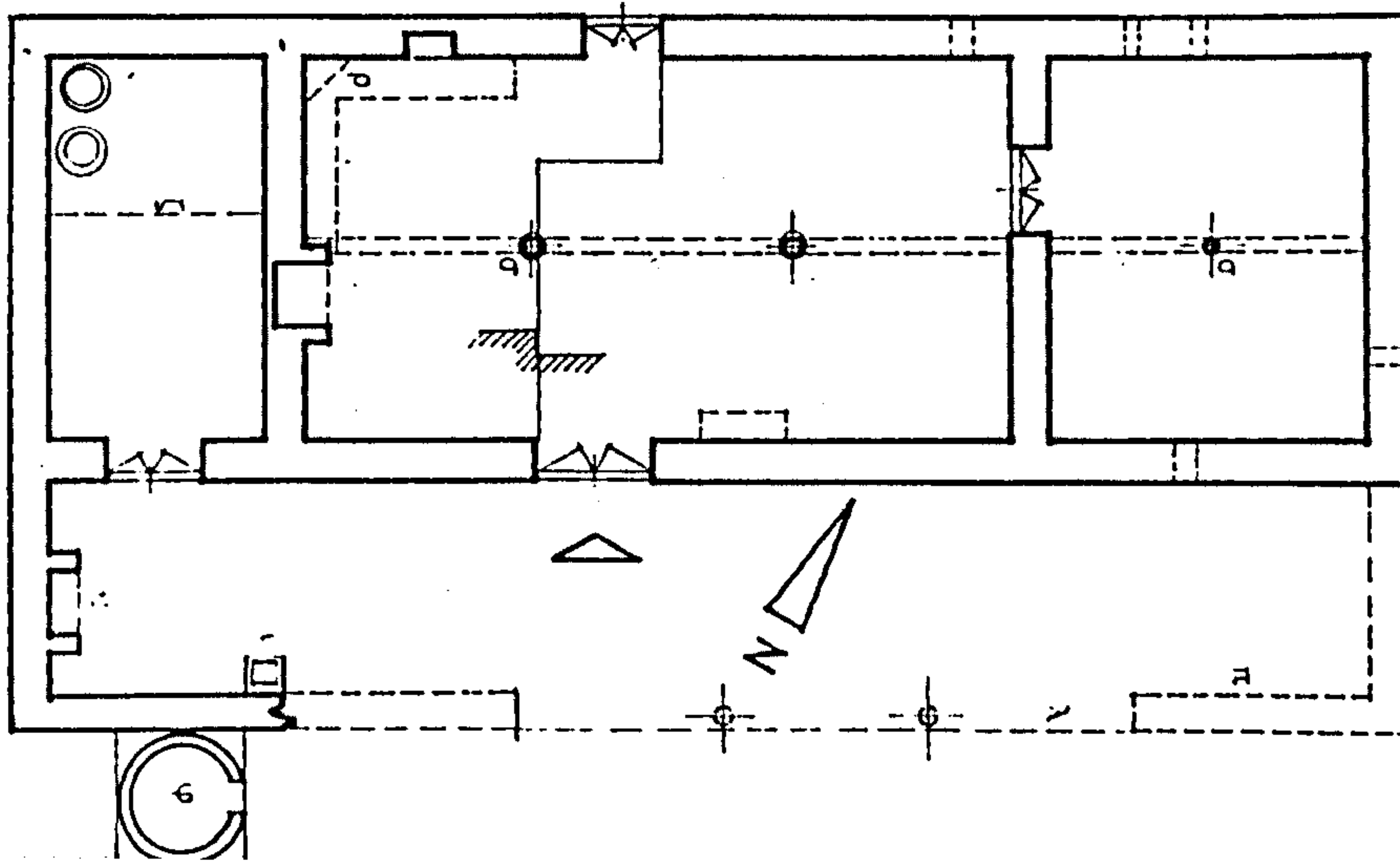
### **The Courtyard**

The courtyard is another building element which acted as a climatic modifier in the Cypriot house. It is an arrangement which evolved naturally from the climatic conditions, the needs of the family and the social structure of the community (*Fig:1.4.3*).

Whether it opens onto the road allowing social contact, or is secluded at the rear of the house for privacy, protected with high abode walls or the house volume itself, it always creates a micro-climate that moderates the climate surrounding the building. Planted mostly with deciduous vegetation like grape-vines, pomegranates, fig trees etc., offers shade in the summer and admits sun in the winter. It also creates windy sides which are most valuable when one seeks the breeze in the summer and calm corners in the winter. Arched arcades at the perimeter are indispensable to shield the overhead midday sun (*Ref:1.8, 1.11*).



Fig. 1.4.1: Evolution of the Cypriot House

(a) "Makrinari"  
(Long Room)(b) "Dhichoron"  
(Double Space Room)(c) "Sospiton"  
(Inner Room)(d) "Heliakos"  
(Solarium)



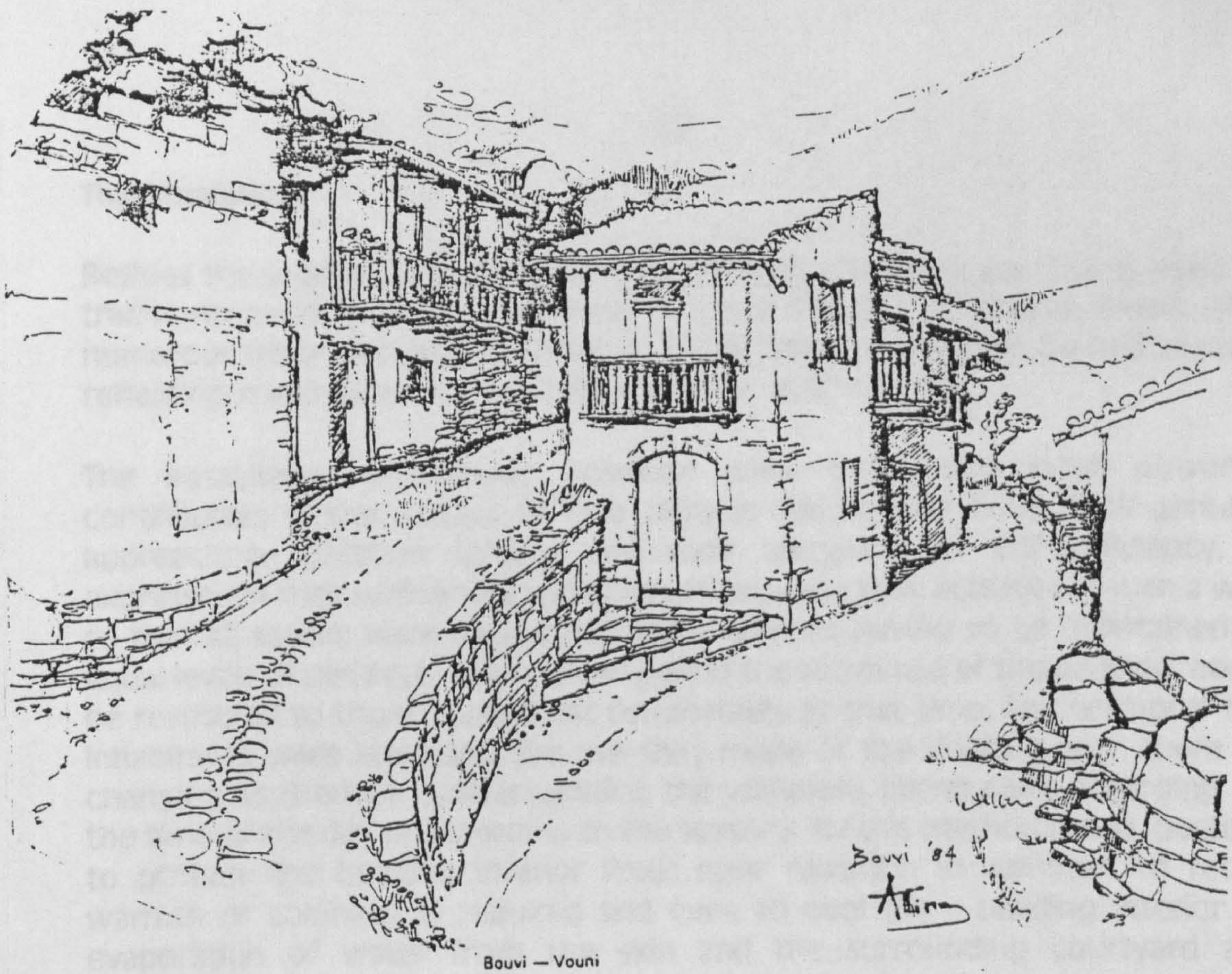
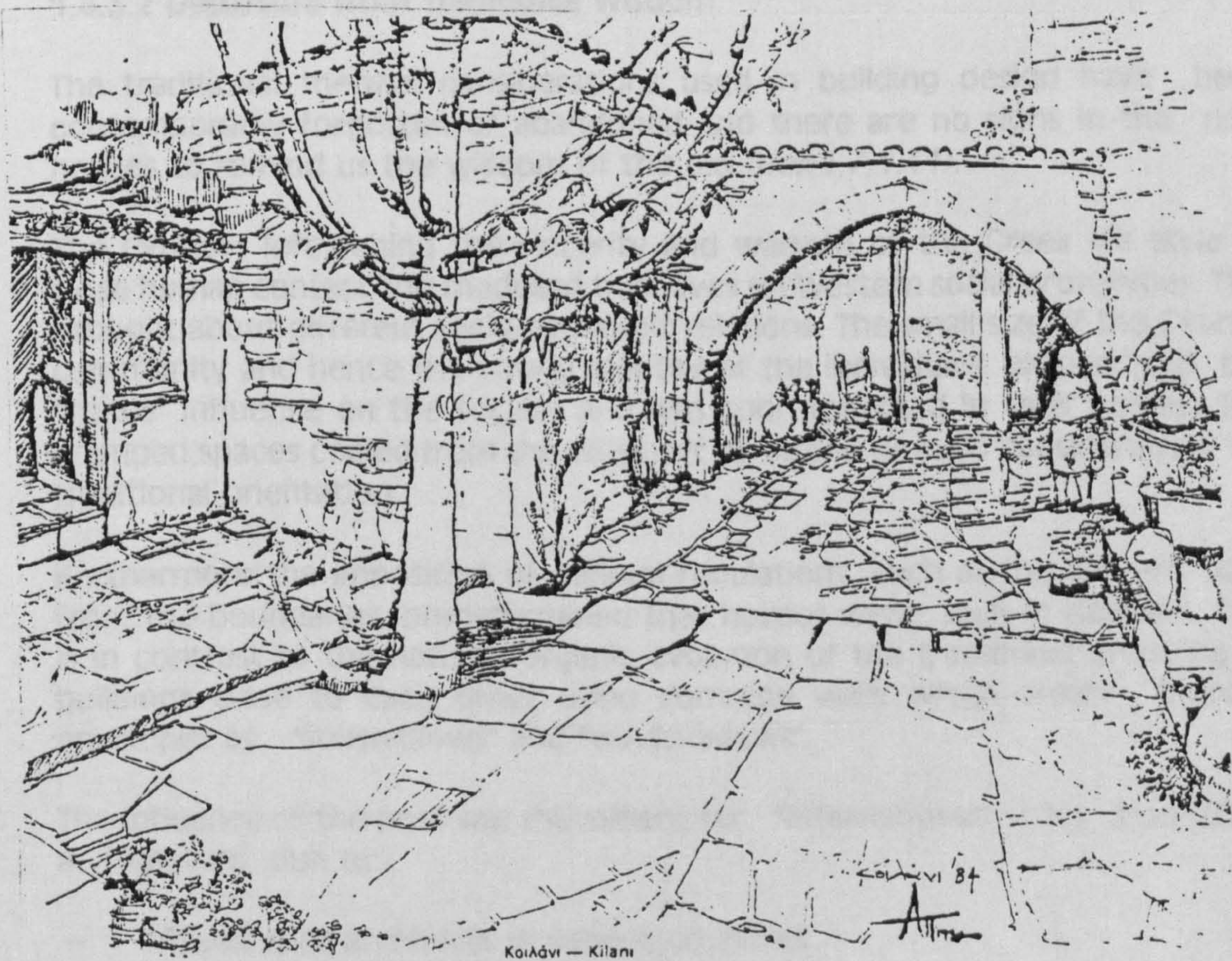


Fig. 1.4.2: Traditional Village





## The Inhabitants

Besides the solarium and the courtyard, the two fundamental means, used in traditional building design, to temper extreme weather conditions, there exist numerous other architectural aspects and building elements in the old houses reflecting the wisdom of tradition {*(Ref:1.11, 1.20(iv), (v))*}.

The inhabitants themselves however were the single most powerful contributors to the success of their climatic designs (*Ref:1.24*). Their genuine approach to problem solving, and their tendency for self-sufficiency, is expressed in their willingness and ability to organise daily activities in such a way so that all spaces were used dynamically without having to be maintained at equal levels of comfort. At any given period the active use of the building could be restricted to those areas most comfortable at that time. Furthermore the inhabitants were attending the use they made of the building and there by changing its thermal characteristics; the variations taking place according to the time of the day or according to the seasons. By this method it was possible to protect the building interior from solar radiation in summer, to retain warmth or coolness as required and even to cool the building interior by evaporation of water from the skin and the surrounding courtyard and vegetation.

### 1.4.3.2 Departure from Traditional Wisdom

The traditional thermal considerations used in building design have been contemporarily forgotten or abandoned and there are no signs in the new houses to remind us the wisdom of the old (*Ref:1.7, 1.11*).

The Cypriots left behind the sincerity and warmth of the Greek life style of close human contact and modelled their lives on Western social prototypes. This brought about different socio-economic relations. The small size of the Cypriot community and hence the strong identity of the individuals, exaggerated the "status" influence on the society and was soon reflected in their homes. The cramped spaces copied from the West left no option or even consideration for traditional orientation.

Furthermore the imposition of general regulations, such as the 3m set back from the boundaries, predetermined that houses were built in isolation. This is in contrast to the natural, organic evolution of the traditional grouping of buildings close to each other using common walls which create thermal envelopes as "sunshadows" and "windshadows".

The influence of the post-war movement for "International", mass production architecture, due to:

- Training of architects in various countries
- Mass media



- Tourism demands
- Uniformity of materials and technology
- Quick, cheap and easy approach to design solutions,

has further resulted in Cypriot buildings which are climatically inept. Buildings no longer act as climatic moderators to soften the unpleasant climatic extremes, an architectural task the traditional wisdom handled skilfully. On the contrary; adoption of international styles aggravated adverse climatic conditions. Adoption of foreign architectural solutions in Cyprus often accentuates the extremes of the climate.

The buildings have become enclosures for artificial environments and often their shells act as an additional obstacle to the efficient use of their mechanical installations. By behaving "worse than the climate itself" such designs demand more consumption of auxiliary energy through mechanical equipment simply to control their indoor environment *{(Ref:1.20(v), 1.26(ii))}*.

In addition to the above influences, there are more interrelated factors which increase the complexity of the architecture of the contemporary Cypriot house.

The trend towards greater standards of comfort in recent years, coupled with the tendency of the human animal to adapt to its environment has led to the increasing use of air conditioning systems, and more energy demand than the common sense approach of our predecessors.

As our society becomes more demanding and litigious, the safety factor in engineering increases not only for present but even more so for future demands. These cost increases are passed on to the ultimate user of the building *(Ref:1.11)*.

#### **1.4.3.3 The Modern Villa**

The architectural scene in Cyprus today is in discord and disharmony with the natural environment. The attempts at originality are obvious in building design, but also obvious is the lack of wisdom to confront the harsh climatic conditions. The result is modern villas which are struggling to achieve indoor comfort conditions and consequently devour large amounts of energy.

Maximum exposure of the external envelope of the house to the sun is inappropriate for Cyprus. It will also be colder in the winter. The tendency to elevate the building on columns (pilotis) with the prospect of integrating shops or stores in the future or to house the car of the family, results in similar problems *(Fig:1.4.4)*. More of the surfaces are exposed to ambient temperature fluctuations. Elevated buildings no longer have that contact with the earth that keeps a constant 10 to 13 degrees centigrade temperature. However with a wind, the raised pilotis creates a higher velocity (venturi effect) of air moving



under the house which causes the temperature to drop significantly. This is convenient in the summer, but detrimental during the winter (*Ref:1.11*).

The modern villa does form a court but it is typically underneath the building with no solar access in winter. It no longer serves as the welcome social, transit space between outside and inside, public and private as the traditional courtyard. Its traditional range of functions; children rearing, containment of the animals, and space to live during the majority of the seasons are reduced to the storage of garbage and car parking.

The solarium is no longer a solar feature or indeed the focal space of the Cypriot house. It became the manifestation of social status and no longer resembles its original form and functions. Its name has also changed; it is replaced by its European version "Entre" and "Hall".

This contemporary scene brings about a sense of nostalgia for the traditional wisdom which may encourage designers to derive lessons from our ancestors (*Ref:1.11*).

#### **1.4.4.0 Transition from Traditional to Contemporary House**

It is evident that the task of modern architects is considerably more complicated than that of indigenous builders. The demands of modern life introduced new factors and considerations into the design of buildings beyond the "basic" traditional ones. As technology advances and life becomes more demanding, the judicious and optimal organization of complex variables involving technical, social, utilitarian and cultural aspects, still converge on creating comfort and convenience to the user. The priority of architects in the design process alters; machines become more important in producing appropriate comfort standards. Moreover as the feeling of comfort is a subjective perception it varies from person to person from culture to culture and over time. So it is unfair and wrong to judge thermal comfort levels in traditional buildings by the same yardstick that we use for modern ones (*Ref:1.8*).

However the tools, materials and techniques available to the modern architect are more than the indigenous builder had access to. In addition the architect has the advantage of the accumulated knowledge of predecessors. It is these messages obtained from the collective creations of the competent, tested, viable Cypriot traditional approach to house building, that is to be discussed in the following notes.

The basic objective is to view the dwelling as the result of a highly complex set of design criteria incorporating cultural, social, educational and technological differences between the old and conventional practice deriving



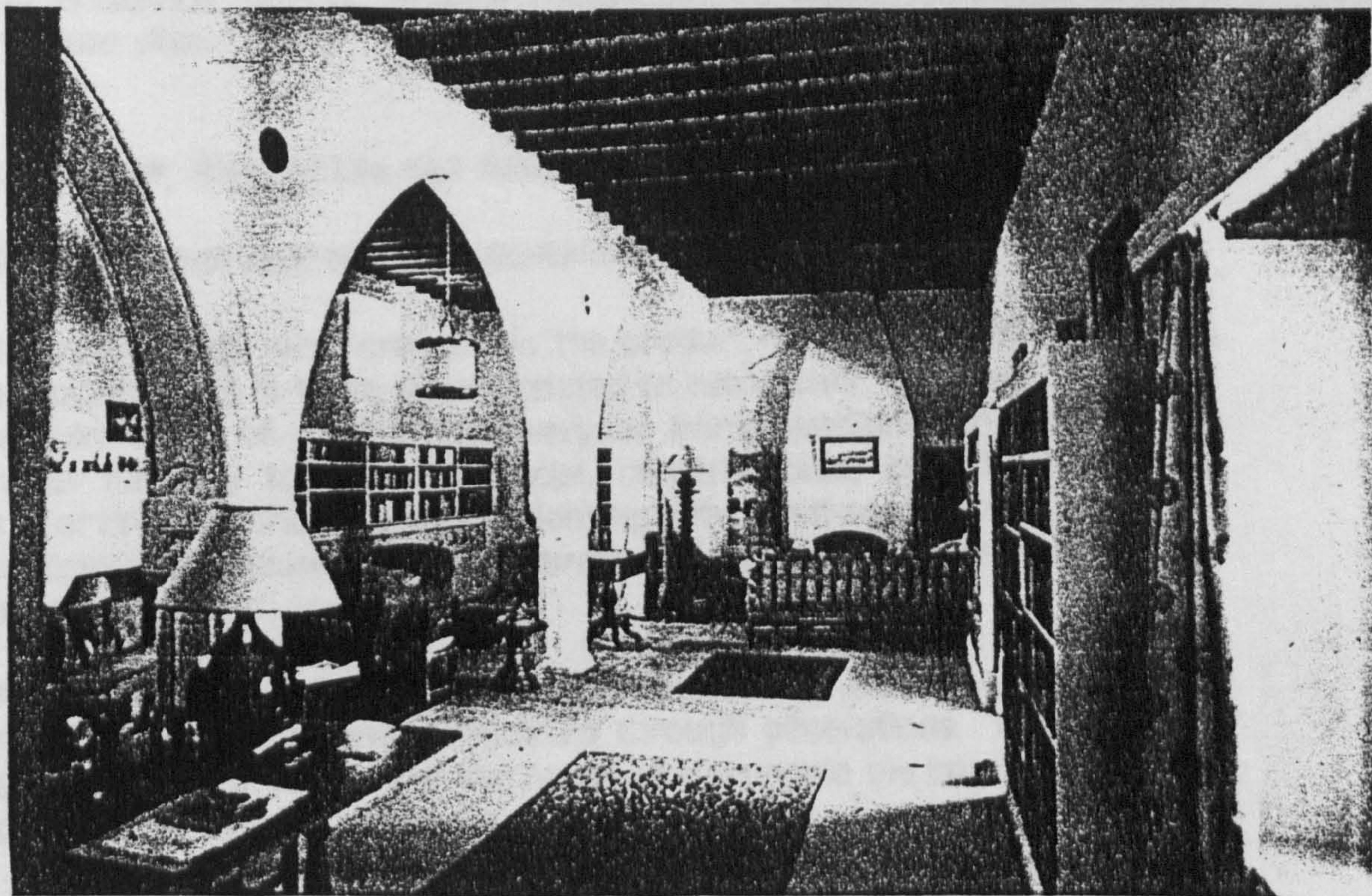


Fig. 1.4.4: Solarium as Internal Space

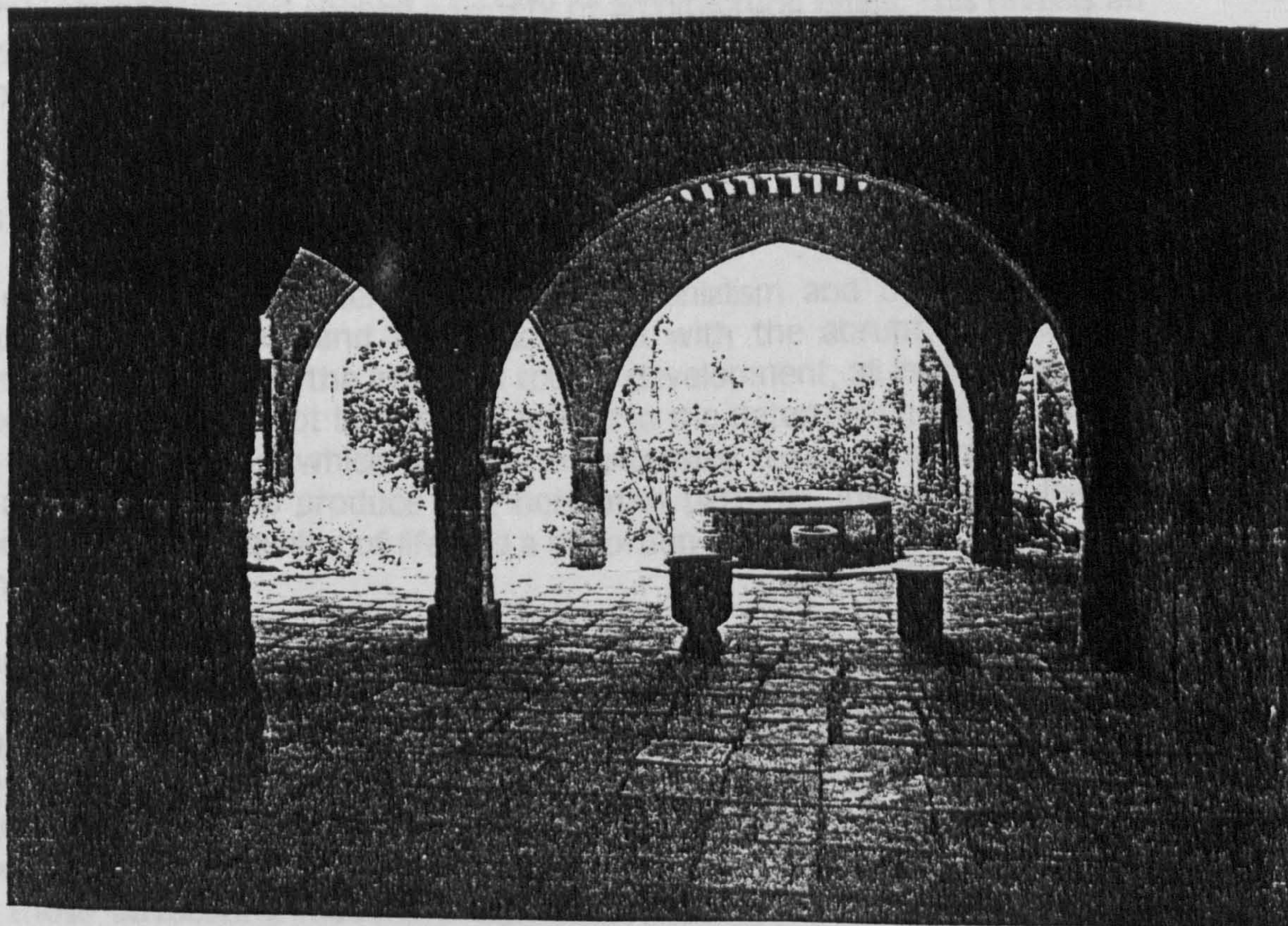


Fig. 1.4.5: Solarium as External Space



recommendations for the efficient utilisation of energy in contemporary architecture (*Ref:1.2*).

#### **1.4.4.1 Culture, Ways of Life and Buildings**

##### **Traditional Integral Approach and Continuity**

Traditional buildings were erected, as the product of a diversity of influences acting together, all of them closely related to each other. They were meeting the requirements of culture and everyday living conditions, demands and restraints be they topographic, social, constructional, climatic, functional, stylistic or financial. The complex relationship between these factors is reflected in the form of the house where their presence will be in accordance with their importance.

Traditional houses evolved as a result of an integrated design approach based on a trial and error process transmitted through generations. It is gradually corrected and adapted to meet the needs of the people the conditions of the environment or even to assimilate foreign influences.

For centuries Cyprus has oscillated between international influences and local themes. However a strong traditional core model has emerged which blended external attractions and shaped a variety of architectural types. This reveals an identity and local meaning as the thread of continuity through the combination of domestic and imported elements.

##### **Disruption of Continuity and Cultural Alienation**

The mass media, the faster pace of life, colonialism and the consequent independence of the island which coincided with the abrupt, oversleeping modern movement and the irrational tourist development, all inflicted sudden changes. These could not be accommodated in the determining factors of the core traditional model which requires an extensive temporal inertia until the trial and error process produce new normative patterns. Instead they lead to the lowering of the quality of life and a distortion of the character and identity of the island.

Emphasis was given to stylistic and new topological and morphological standards, which prevailed upon indigenous traditional values. There was a tendency to disregard all other considerations and to sweep aside all local specific conditions such as climate, social and cultural patterns (*Ref.1.7(i),(ii)*). Architects are faced with the dilemma of designing quickly for a society divided between, a faction seeking the fulfilment of a private, traditionally driven life and those advocating modern design and progress. Time pressure, financial considerations, image and fashion together with strict planning and design regulations do not offer the architect flexible design solutions.



Unfortunately, designers frequently sought a resurgence of past forms by imposing traditional patterns on new buildings in the form of textured arcades, facades, and misplaced traditional elements and ornaments. In an effort to give the illusion of Cypriot identity, the essence of Cypriot architecture is bastardized.

Other designers have completely ignored the past and transposed plans from the west that are better fitted to industrialised societies. These designs have been transposed to the Cypriot environment with no effort at social or climatic adaptability. They indulge in the transfer of technology and foreign ideas to the detriment of the local population resulting in cultural and architectural alienation.

Both ideologies fail to respond efficiently to the island's society which is in a state of transition searching for a new identity and a suitable built environment. Echoing the past is not recommended and turning to the west for architectural solutions that are inappropriate for the island are also misleading.

As far as the thermal problems of buildings are concerned, in conventional forms of architecture, it would be wrong to permit special technicians to design and calculate certain installations that will correct the interior conditions. There is also a tendency today to apply passive heating or cooling systems to projects that are incorrectly conceived. Adopting such strategies ignores the fact that the environmental functions of a building depend on the initial decisions taken on the project as an integral part of many others.

### **Reconciliation of Traditional and Contemporary**

It is true that we cannot go back to the morphological structures or in deed life style of the traditional house as the ideal model. Although this form of building fulfilled social and cultural needs and responded to the comfort requirements at the time, it is no longer valid in the light of today's economic situation and life-style. Attempts to return to traditional forms in the design of buildings, assuming that they can retain their intrinsic qualities as climatic modifiers and comfort creating environments, is fallacious. There is an ideological tendency revealing itself all over the world in the production of vernacular souvenirs which perform no better than their modern counterparts.

The pace of life cannot be altered or halted. External influences and technological advances cannot be ignored or rejected. Human needs and especially comfort criteria are different today from those of our predecessors but even so they tend to be similar even in different cultures.

It is possible to support the development of a contemporary local architecture through the restoration of design complexities compatible with in digeneous culture, social needs, and specific needs of the inhabitants within an approach centred on climatic conditions which contribute to the promotion of passive



low-energy design.

The conditions of the locality is what is left as the only constant undoubtful reference on which to base the formation, selection and application of appropriate design criteria. This approach combined with renewal of interest in those aspects of architecture which contributed to thermal comfort in a building is likely to reconcile the traditional with the contemporary.

#### **1.4.4.2 Topoclimatic Conditions - Natural and Man-made Laws**

##### **Natural Laws**

In addition to the socio-cultural setting, vernacular architecture was also a direct response to the possibilities and limitations, of the natural environment. Traditionally the anonymous designer has endeavoured to understand nature in order to create a healthy environment, through a respect for the natural and acquired conditions and laws which particularly marked that location. Climatic characteristics played the leading role amongst the determining factors of the vernacular architecture. They affected and shaped the character of the built environment so that the inhabitants learned to live in peace with nature and not to confront it.

##### **Acquired and Man-made Laws**

In contemporary houses, acquired cultural, social and man-made laws prevail. The recent urbanisation movement of the last three decades (1960-90) threatens to destroy the qualities and values reflected in ecologically sound buildings, whose elements are sympathetic to the idea of close links with nature. Building codes, regulations, and centralised planning are amongst the factors responsible for the form of our built environment both on the architectural and urban levels limiting adaptation to a location. This prevents the creation of individual architecture which is organically united with the nature of the area. Every location has absolutely individual characteristics which are part of the conditions for such buildings.

##### **Return to Nature**

Social and man-made laws change but nature with its peculiarities of climate and landscapes on the whole remains permanent.

Yet nature must be viewed by the designer as a system, a complex of features interrelating and dependent on each other which if combined in different ways in the different situations, require specific architectural solutions.



Each natural situation demands a scrutiny of its specific characteristics so as to utilize the geographical climatic resources to control or isolate environmental aspects. The optimal microclimate in the building and its surroundings is sought and dwellings should evolve as an integral part of the ecological system.

In searching for ways to revive the unity between nature and architecture, vernacular architecture could be used as a source of inspiration to achieve an organic solution to the design of the house and its natural surroundings. Vernacular and traditional architecture achieved a beauty which derives from the natural environment and inherently provides aesthetic qualities, climatic adaptability and economic feasibility. An in depth study of indigenous structures could re-introduce the principles of bioclimatic design which could well be adapted to our present architecture.

Furthermore regulations must be reviewed in order to provide a more flexible framework to accommodate these principles and allow each case to be evaluated on its own merits by the designer.

#### **1.4.4.3 Buildings - Education - Knowledge - Evaluation**

##### **Trial and Error**

As previously mentioned the development of vernacular architecture was derived from a continuous design process of trial and error. Foreign influences and leaps of originality if they worked were employed and assimilated, if they did not they were abandoned.

##### **Buildings Ad-hoc**

Today local architects are not trained in their own traditions. Education is derived from Western schools lacking the emphasis on cultural values and stressing western design principles. There is lack of cohesion in the architectural vocabulary resulting in "villas" that fulfil basic social and spatial requirements, but do not and cannot operate without air conditioning. Even when architects have a knowledge of their own traditions and culture they tend to reject it as old fashioned.

There mainly prevails borrowing forms ad-hoc with main criterion the impact the design has on people.



### **Widening the Spectrum of knowledge**

The trial and error method by which vernacular architecture was built, evolved and tested is not applicable to the pace of life today. In a period of rapid changes in building design technology, old methods of gradual improvement and testing cannot cope.

Equally quick and simultaneously efficient methods are needed to respond to modern demands, to the newly recognized ecological needs and to economic pressures. This is done today with bioclimatic architecture and the use of computer simulations which permit a rapid prediction of building performance. Case studies are however the most convincing means by which buildings are observed to be in harmony with climatic variables.

Therefore what is needed, in the fast moving world of today in order to investigate suitable design aspects, is to widen the spectrum of knowledge. This could be achieved through education. Through education the knowledge base is extended to more architectural opportunities as well as measurement and evaluation aspects. Consequently measuring the performance of indigenous architecture will improve sensitivity towards it and reinforce an appreciation of its values. Such learning from the past will assist in extending our understanding of traditional architectural solutions, especially our present day response to the various bioclimatic problems.

Through the broadening of the spectrum of knowledge and with the increased availability of computer modelling techniques and other aids, it is possible to exploit new design possibilities by predicting reasonably accurately the thermal behaviour of a structure under various climatic conditions.

This in effect, could improve the thermal efficiency of future houses so that they become more climatically responsive.

#### **1.4.4.4 Technology and Comfort**

##### **Natural resources**

Vernacular Cypriot architecture even when it is sited in parts of the island with extremely harsh conditions (Troodos mountains and Messaoria plains), by incorporating various passive cooling and heating methods in buildings, has tackled the issue of climatic regulation and efficiency. It relies only on imaginative techniques and the natural means locally available. These traditionally created solutions for better human comfort undeniably enjoy positive aspects. Buildings were basically maintenance free, they used no other form of energy than natural forces, they do not pollute the environment and they are economical to build.



## **Mechanical Means**

Technological innovation and economic development have brought major changes to the architecture of Cyprus without successfully answering the social and physical problems in the design of housing on the island.

Architects today bypass the sensitive issue of climatic control. Although they have at their disposal a rich variety of methods to provide comfort in building spaces. It has become a common tendency to rely entirely on engineers proposals for sophisticated systems and equipment. Yet engineers who are educated on a different basis from architects, are inclined in most cases to perceive buildings as pieces of machinery rather than as spaces to live in, to experience and to remember. This attitude perpetuates its own problems besides the inherent negative feelings many people feel for mechanical systems:

- a) The initial cost of buildings rises considerably due to the expense of purchase and installation of the mechanical equipment.
- b) The sophisticated systems require specialized design and computation services.
- c) The smooth functioning of artificial systems requires costly maintenance which in turn, demands experts and spare parts.
- d) In addition, the continuous need for energy over the life of the building, which is in short supply or may be very expensive.
- e) The sophisticated mechanical equipment occupies large spaces which interfere with the building's spatial system and their anaesthetic appearance directs or even focuses design on their camouflage by false ceilings or partitions.
- f) They are accompanied by other environmental drawbacks such as pollution through their waste products, noise, vibration in buildings and other potential hazards.

## **Nature and Technology**

It is an unrealistic proposition to blindly reject what modern technology provides us with today in ensuring a better building environment in contemporary houses. However, instead of relying entirely on mechanical means the designers should direct their efforts towards achieving the best possible climatic ambience control, through meaningful and wise architectural design which employs a multitude of natural solutions. The artificial processes of modern technology may then be used to augment and complement the climatization if necessary. Solving contemporary problems by modern technology and natural means could be used to relate to the local social and physical environment achieving integration of modern technology and



traditional wisdom.

#### **1.4.5 Conclusive Approach for Energy Efficient Houses**

It is concluded that successful climatic design in Cyprus should not ignore the accumulated experience and wisdom of our forebears but rather it should develop after a deep understanding, through scientific comprehension, rather than an emotional appraisal of traditional architecture.

On the other hand, the mass knowledge and technology coming from the West should not be ignored either. The architecture must be a synthesis of both aspects so that it is in harmony with the traditional values suitable for the contemporary Cypriot society, its cultural identity and human scale and based on the appropriate technology.

On a more practical level the promotion of energy efficient construction necessitates encouragement of important modifications in the design approach of buildings and the involvement of all public, private and professional parties presently in charge of the construction sector.

Within the above approach the consequent work was developed with the intention of proposing guidelines on the energy conservation of house design issues at its conclusion.



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## **CHAPTER 2**

# **BIOCLIMATIC ANALYSIS**



## **2.0 BIOCLIMATIC ANALYSIS**

### **2.1 CLIMATIC CONDITIONS IN CYPRUS**

#### **2.1.1 General**

In order to assess the energy demands for heating and cooling in domestic buildings and evaluate the free energy systems available to contribute to these requirements, the local climatic conditions must be carefully considered and analyzed.

The climate of a region is determined by its geographical position, the morphology of the ground and the meteorological manifestations of the region.

In describing the climate of Cyprus, the meteorological features of the Eastern Mediterranean are examined in the following clauses (for the geography and morphology (1.1.1"Main Geographical Features").

Also a brief description of the most important climatic elements of Cyprus is given with specific reference to its basic climatic sub-types.

#### **2.1.2 Synoptic Meteorological Features**

The activities of certain pressure systems from Atlantic, Eurasia and Africa (*Map 2.1*) together with the semi-permanent synoptic features of the upper atmosphere, affect the climate in the Eastern Mediterranean in both cool and warm seasons. The resulting winds, cause unstable weather patterns in Cyprus, and air masses of different origin.

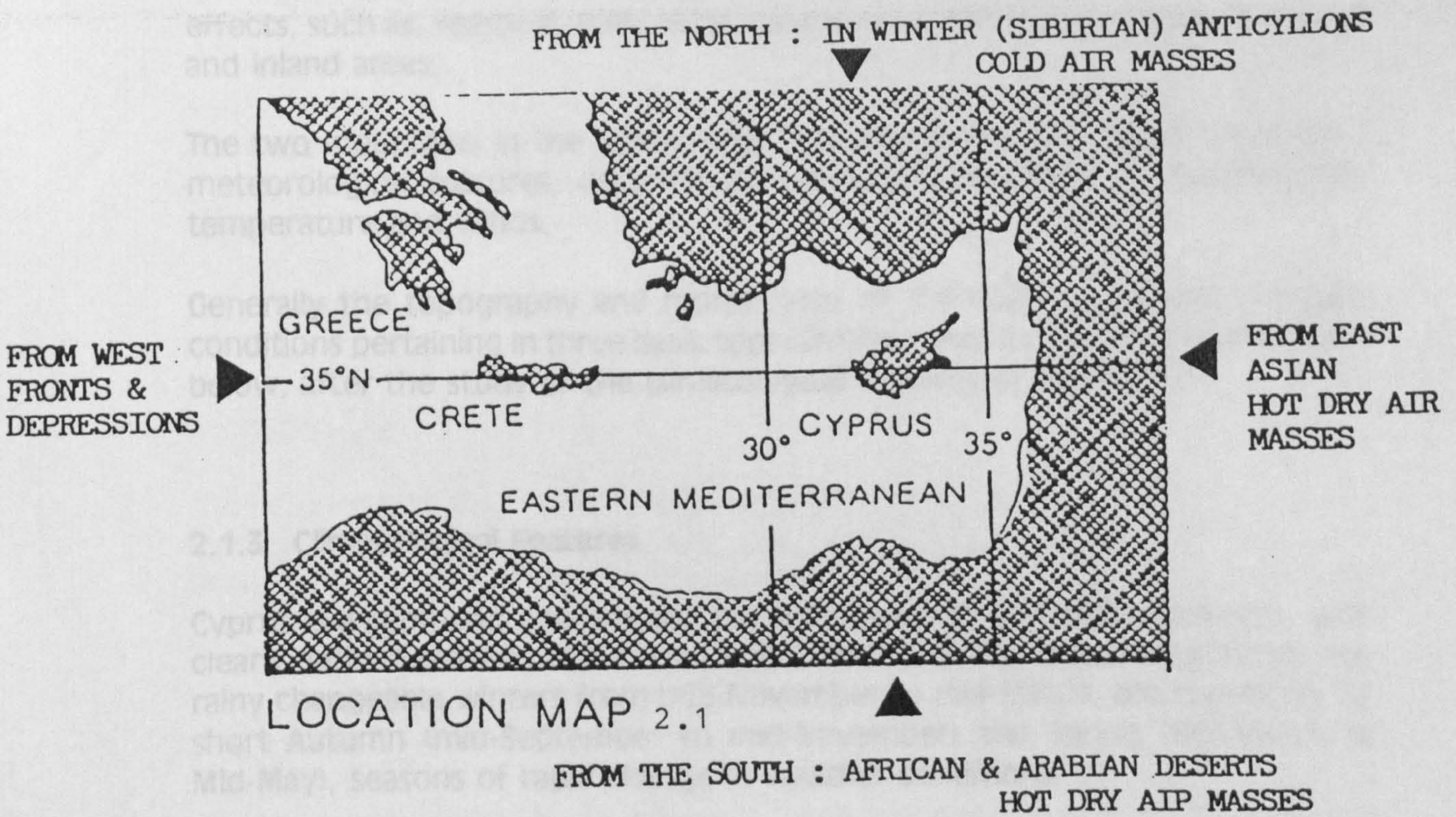
In Winter cold air streams approach Cyprus from the North. Unstable weather systems from the Atlantic, moving eastward across the Northern Europe and air masses from the Arctic via the Norwegian sea from West to East, cause disturbed weather in Cyprus, usually lasting for one to three days and result in most of the annual precipitation .

During Spring and Autumn, the collapse of the Siberian Winter anticyclone, the rapid development of the continental depression over South-West Asia, its extension to Asia Minor, and the low pressure over the heated Sahara, define the two seasons as transitional with long periods of settled weather.

In Summer, low pressures over South-West Asia and the heated Sahara have a major influence on the island causing high temperatures, almost cloudless skies and negligible precipitation.

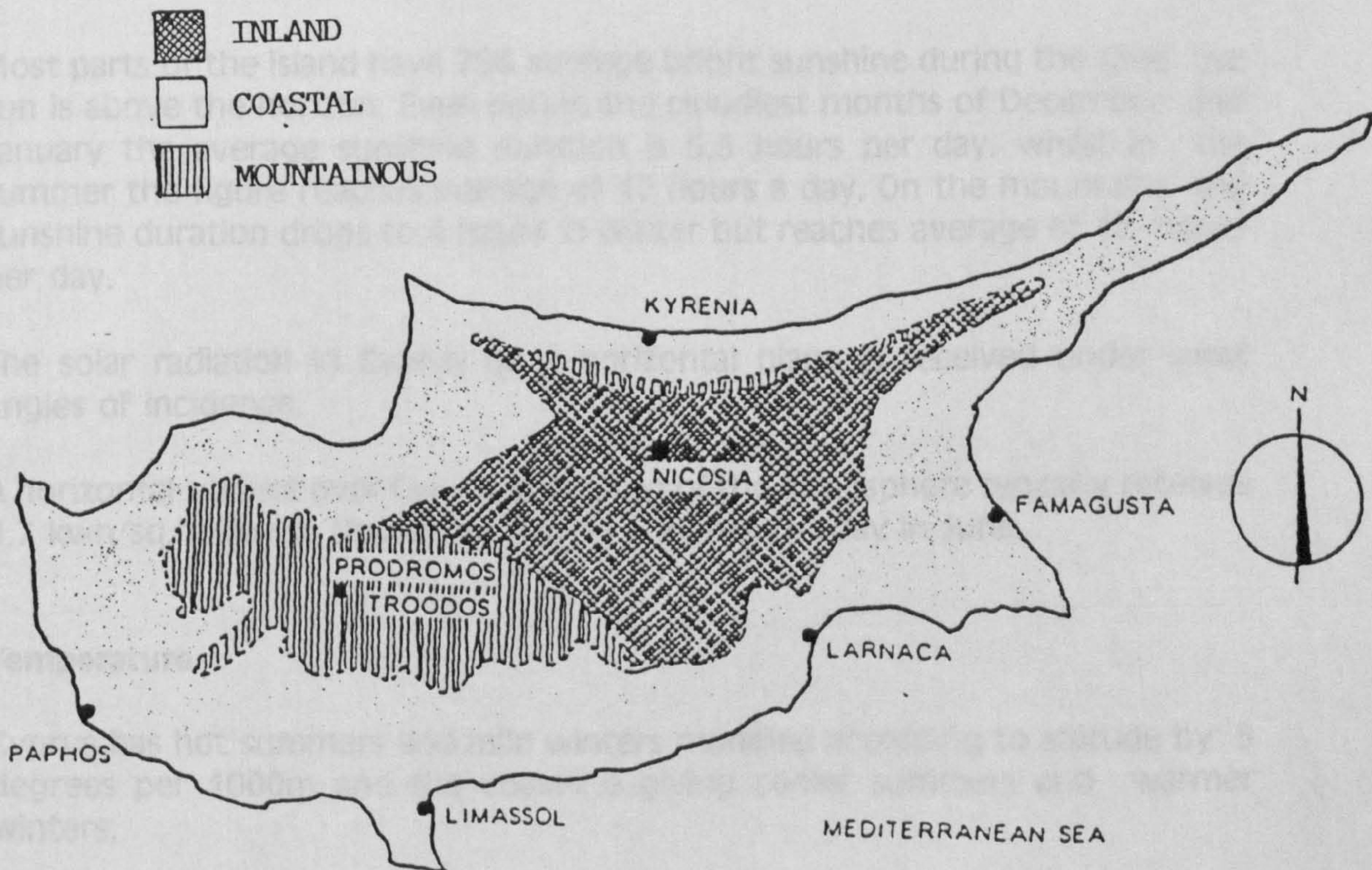
The predominantly clear skies and the high levels of solar energy, result in local





# TOPOCLIMATIC ZONING ZONES

MAP: 2.2





effects, such as, seasonal, daily, large temperature differences between coastal and inland areas.

The two mountains in the island (*Map 2.2*), also affect the above mentioned meteorological features, determining mainly the patterns of precipitation, temperature and winds.

Generally the topography and morphology of the island determine climatic conditions pertaining in three basic topoclimatic zones as defined and examined below, after the study of the climatological features of the island.

### **2.1.3 Climatological Features**

Cyprus is a semi-arid country and has an intense Mediterranean climate with clearly defined seasons. Hot dry summers from mid-May to mid-September and rainy changeable winters from mid-November to mid-March, are separated by short Autumn (mid-September to mid-November) and Spring (Mid-March to Mid-May), seasons of rapid change in weather conditions.

The most important climatic elements are examined herebelow.

#### **Solar Radiation and Sunshine Duration**

Solar Radiation statistics show that Cyprus enjoys a very sunny climate compared with most countries.

Most parts of the island have 75% average bright sunshine during the time the sun is above the horizon. Even during the cloudiest months of December and January the average sunshine duration is 5.5 hours per day, whilst in the summer the figure reaches average of 12 hours a day. On the mountains the sunshine duration drops to 4 hours in winter but reaches average of 12 hours per day.

The solar radiation in Cyprus on a horizontal plane is received under small angles of incidence.

A horizontal surface over Cyprus at the top of the atmosphere typically receives 4.7 kwh/sq.m/day in December and 11.6 kwh/sq.m/day in June.

#### **Temperature**

Cyprus has hot summers and mild winters modified according to altitude by 5 degrees per 1000m and the coastline giving cooler summers and warmer winters.



The seasonal and diurnal differences are large. Between mid-summer and mid-winter, temperatures vary from 14 degrees Celsius on the coast to 18 degrees inland. Temperature difference between day maximum and night minimum varies in winter from 8 to 10 degrees on the lowlands, 5 to 6 degrees on the mountains whilst in the summer increases to 16 degrees on the lowlands and 9 to 12 degrees elsewhere.

Frosts are rarely severe but are frequent in winter and inland during spring.

### **Humidity**

Humidity of air varies from 35% in the summer to 85% in winter and at night, throughout the year. To a large extent it reflects the inverse relationship to the yearly large temperature differences. Besides the seasons the elevation above mean sea level and distance from the coast also affect the relative humidity.

### **Precipitation**

Although precipitation is not a determining bioclimatic design factor, it is worth mentioning that in Cyprus this is generally low, occurring in winter and increasing in the mountainous areas. It usually averages 477 mm and from about 40 rainy days ( with precipitation 0.2 mm or more ) in the south eastern part of the island, to about 80 to the high mountains .

### **Evaporation**

The evaporation of water over Cyprus is strong, due to the intense solar insolation and the strong "drying power" of the air; it varies according to location and the exposure of the measuring instrument.

### **Winds**

Winds in Eastern Mediterranean are mostly westerly or southwesterly in winter and northwesterly or northerly in the summer.

The wind strengths are moderate, rarely reaching gale force. Gales are infrequent inland, but many occur on exposed coasts with winter depressions. Small whirl winds appear midday in summer on the hot, dry central plain. In mountainous areas there are local winds (anabatic and catabatic), and the orography determines wind strength and direction. On coastal areas there are land and sea breezes due to the local heating effects.



Generally the winds inland are variable in direction and moderate in strength. The predominant clear skies in the summer and the large temperature differences between sea and land often cause penetration of these breezes inland to reach it from west, east, and south-east moderating high temperatures and increasing humidity.

In the cool season the most frequent winds inland are southerly to westerly in the mornings and northerly to easterly to south-easterly in the afternoons. South-easterlies appear to be more or less constant in direction through out the year. The strongest winds (7 Beaufort and over) but of low frequency are the northerlies to easterlies.

#### **2.1.4 Topoclimatic Zones**

The sea that surrounds the island, its morphology with its varied elevation, and its prevailing winds determine the climatic elements which in turn define three main topoclimatic zones in Cyprus:

- a) **Inland**
- b) **Coastal**
- c) **Mountainous**

*(Map 2.2 and fig 2.1)*

The representative climatological stations of the topoclimatic zones, their climatic sub-type and their broad characteristics are as follows:

<b>a) Inland</b>	<b>Continental Mediterranean</b>
<b>Station</b>	— Nicosia.
<b>Elevation</b>	— 0-200m.
<b>Winds</b>	— Variable often light.
<b>Temperatures</b>	— High mean temperature.
	— Large seasonal change.
	— Very large diurnal fluctuation.
<b>b) Coastal</b>	<b>— Marine</b>
<b>Station</b>	— Limassol.
<b>Elevation</b>	— 0-200m.
<b>Winds</b>	— Much affected by sea breezes.
<b>Temperatures</b>	— High mean temperatures.
	— Small Seasonal changes.
	— Small diurnal fluctuation.



- c) Mountains**                    **— Mountainous Mediterranean**
- Station**                        **—** Prodomos.
- Elevation**                    **—** 200-1951m.
- Winds**                        **—** High mountains exposed to surface winds.
- Temperatures**               **—** Moderate to low varying with height.  
                                      Large to moderate seasonal change.
- Small diurnal change especially winter on the high mountain.



21.5 Characteristics of Climatological Stations

The following <sup>own</sup> table defines the location of representative stations of the topoclimatic zones and gives basic records for radiation, temperatures, relative humidity, wind force and direction.

Table 2.1 : Climatological Stations

Station	NICOSIA		LIMASSOL		PRODHROMOS	
Zone	Inland		Coastal		Mountains	
Latitude	35	09 N	34	41 N	34	57 N
Longitude	33	21 E	33	03 E	32	50 E
Attitude	160m		30m		1380m	

	JAN	JUL	JAN	JUL	JAN	JUL
Radiation						
Mean monthly KWh/m <sup>2</sup> /day	2.2	6.9	2.3	7.2	1.9	6.5
Temerature C						
Mean daily	10.2	29.1	12.2.	26.7	3.1	22.3
Mean Max.	15.3	36.7	16.9	32.6	5.9	27.1
Mean Min.	5.3	21.4	7.5	21.1	0.5	17.5
Diurnal Range	9.8	15.4	9.4	13.1	5.0	8.5
Mean R.H %						
08 00 hrs	83	49	76	61	78	34
14 00 hrs	57	28	59	51	79	41
Wind at 10 Metres						
08 00 hrs	230/ 3.3	090/ 3.6	360/ 5.0	270/ 4.3	050/ 4.7	180/ 5.4
14-0 00 hrs	270/ 4.7	270/ 5.2	270/' 9.9	230/ 10.2	180/ 6.4	180/ 6.9
	Direction in Degrees, Speed in Knots					



## 2.2 PHYSIOLOGICAL COMFORT IN THE CYPRIOT HOUSE

### 2.2.1 General

The success of the bioclimatic design of a building is concluded by the evaluation of its performance, determined by the thermal characteristics of the building and the external climatic conditions. Such evaluation is based on the comparison of the resulting indoor thermal conditions of the building with the desired indoors environmental comfort conditions and consequently by the cooling and heating required for achieving such conditions.

In the following clauses the relation of physiological comfort and the weather and climate of Cyprus is examined, using the concept of the "Effective Temperature" and the "Discomfort Bioclimatic" indices.

Also, using the bioclimatic chart drawn for Nicosia the appropriate design strategies are outlined.

### 2.2.2 Climate and Physiological Comfort in Cyprus

The physiological comfort is closely related to weather and climate. The most important climatic elements affecting human comfort are temperature, humidity, sunshine, and wind.

The degree to which an individual is affected by weather and climatic conditions varies as a function of different parameters. The climatic experience, age, state of health, hereditary characteristics, the quality of food, the clothing and the way of life as a result of education are factors which differentiate the biological reactions to weather and climatic conditions.

Various bioclimatic indices have been proposed to indicate the comfort zone, the range of weather conditions which induce the sensation of comfort, the thermal condition without cold stress and heat stress, terms used to express the unpleasant feeling caused by cold and hot environment respectively.

The Meteorological Service in Cyprus (*Ref:2.3*) concluded to an indication of the physiological comfort in the various areas of the island, by using as variant of the effective temperature the discomfort index of Thom.

For the calculations, four areas in Cyprus were chosen as follows :

- |              |                                    |
|--------------|------------------------------------|
| 1) Nicosia   | — Central plain. Elevation 160m.   |
| 2) Limassol  | — South coast. Elevation 3m.       |
| 3) Polis     | — North west coast. Elevation 15m  |
| 4) Prodromos | — High mountains. Elevation 1380m. |



The recordings of dry and wet bulb temperature at 0800 hrs LST and at 1300 hrs LST (for Nicosia at 1400 hrs LST) in the period of 1982-1985 were used.

The annual range of effective temperatures representing the indoor comfort zone is taken between 18.3 and 31.1 degrees Celsius.

From the study is concluded that:

- a) In the mornings the effective temperatures are in the comfort zone in the period from April to November, in the plain areas ( inland and coastal), while on the high mountains the corresponding period is from June to September.
- b) In the afternoons the effective temperatures are in the comfort zone from January to May and from October to December in the plain areas and from May to October on the high mountains.
- c) Cold stress is experienced in the plain areas in the mornings of the winter months and on the high mountains through out the day from late autumn to early spring.
- d) Heat stress is experienced in the plain areas from June to September mainly in the afternoon hours. Heat stress is never experienced on the mountains.
- e) Although the hours of the day for which the calculations were carried out are the most acute hours regarding heat and cold, nevertheless the effective temperatures do not fall below 5 degrees Celsius at Prodromos and do not rise above 28 degrees in Nicosia.

These results, besides defining the problematic daily and seasonal periods in terms of heat and cold and the extend of comfort period in the plain and mountainous areas of Cyprus, they also form a useful guide for building thermal analysis in these areas.

### **2.2.3 Bioclimatic Chart and Design Strategies for Nicosia.**

#### **General**

Considering the climatic conditions of a location and through bioclimatic chart analysis, combining the major climatic variables for human comfort (2.2.2 "Climate and Physiological Comfort in Cyprus"), it is possible to outline the appropriate architectural strategies, for average climatic conditions, that would result to indoors thermal comfort for that location.

Such a bioclimatic analysis is particularly important for preliminary architectural



designs. The selection of the appropriate design strategies, derived from a bioclimatic analysis, compatible with each other and other architectural aspects, could considerably reduce the cost of a building by minimizing the mechanical means for cooling and heating.

As Nicosia has been defined as the selected location for the study (1.3.7), the following bioclimatic analysis will focus for this location.

### **Requirements, Limitations, Scope**

The climatic data required for the plots on the bioclimatic chart are the maximum and minimum of the dry bulb temperature and the coincident relative humidity values, either monthly or hourly.

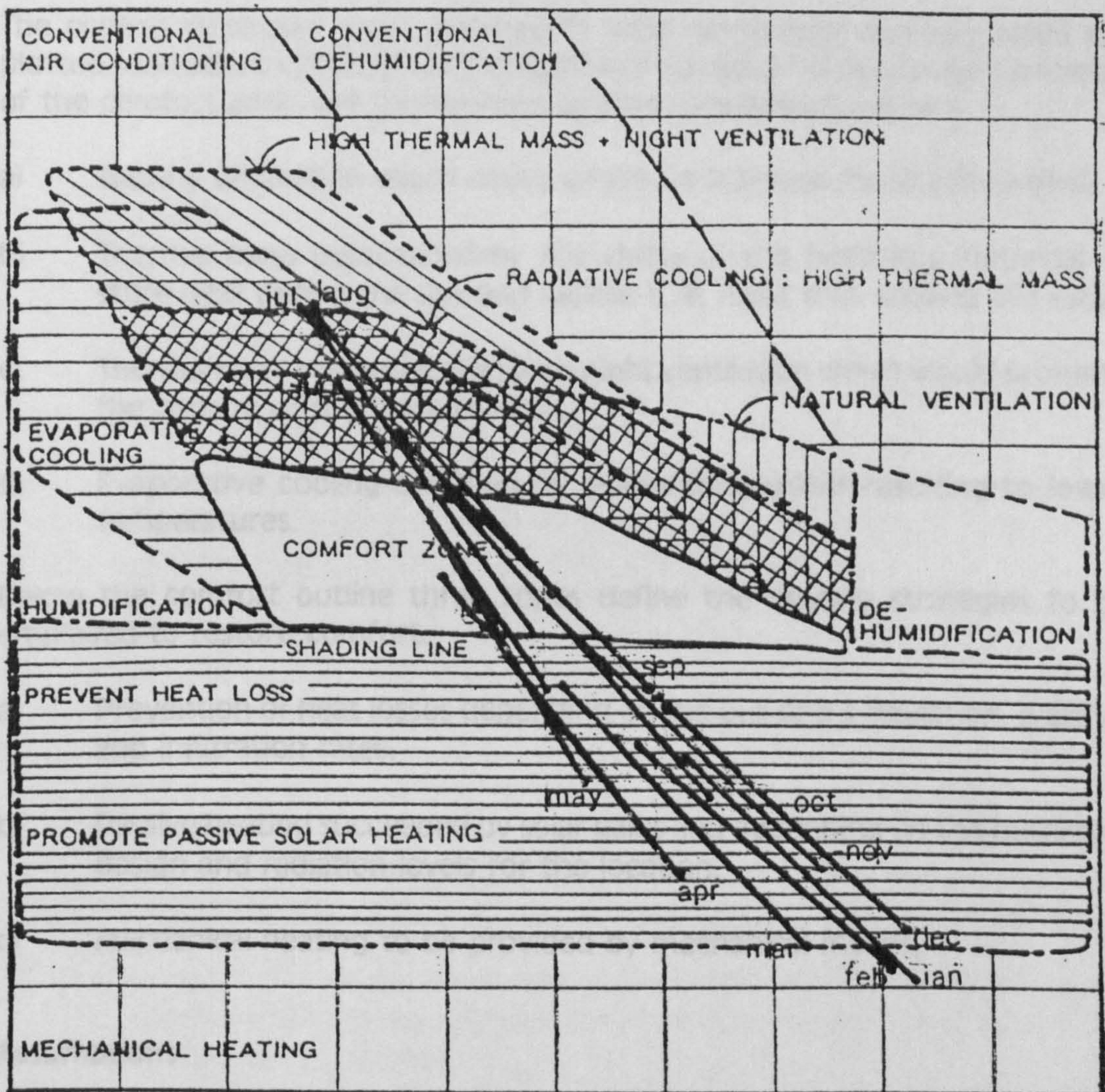
The resultant plots represent outdoor conditions, and the changes of the microclimate of the building depend on many factors such as its size, the thermal lag of its materials, and its infiltration rate. Nevertheless the plots clearly indicate whether the resulting climatic conditions of the location of the building are comfortable, too hot, or too cold. Further to this, subdivisions of the chart into zones (*Graph 2.1*) define passive solar heating and cooling strategies, for restoring comfort, in the different months of the various seasons for a climate.

### **Interpretation**

The interpretation of the figures on the bioclimatic chart illustrated in graph 2.1 could be summed up in the following:

- a) The area of the trapezoid defines the comfort zone.
- b) If the combination of temperature and humidity lies above the shading line then shading is assumed.
- c) If the combination of temperature and humidity lies below the wind line, still air is assumed.
- d) The horizontal lines drawn below the shading line indicate the increments of solar radiation ( direct and diffuse ) falling on a horizontal surface that can compensate the corresponding low air temperatures.
- e) The dotted lines on the left hand side, above the comfort zone, indicate the amount of evaporation in grams, required per kilogram of dry air (2g/kg) to provide the cooling needed for comfortable conditions.
- f) The lines on the right hand side above the comfort zone indicate the wind velocity necessary to produce the cooling effect for comfort.





The following assumptions were made for the bioclimatic analysis. Graph 2.1 is intended as a pre-design guide for Nicosia.

### Graph 2.1

#### BIOCLIMATIC DESIGN STRATEGIES

small internal heat gains (maximum 500Wm<sup>2</sup>/day/person), the following were also assumed:

1) The clothing has a level of 0.3 clo for winter and 0.4 clo for summer comfort.

2) The activity level is taken as 1.3 Met, equivalent to slow walking or light work.

3) The radiation figures to compensate for the extra heat loss at low temperatures are plotted for Cyprus for an average wind velocity of 3 m/s.

4) An average day for each month of the year is given in the bioclimatic chart to be used for the selection of the design strategies. The average maximum temperature is used for the selection of the design strategies.



The cooling strategies to be adopted in order to restore comfort when the plotted, coincident values of temperature and humidity fall above the perimeter of the comfort zone, are represented by four overlapping zones:

- a) Natural ventilation which could simply be achieved by air movement.
- b) Thermal mass determined by the ability of the building's materials to store heat during the day and radiate it at night thus cooling the mass.
- c) Thermal mass in combination with night ventilation which would promote the cooling of the mass at night.
- d) Evaporative cooling achieved by evaporating water resulting to lower temperatures.

Below the comfort outline three zones define the heating strategies to be employed to restore comfort:

- a) Prevention of heat losses depending on the building's insulation, glazing, and infiltration rates.
- b) Passive heating succeeded by solar gains and depending on the building's design and radiation levels for the location.
- c) Mechanical heating to be provided by mechanical means.

### Assumptions

The following assumptions were made for the bioclimatic analysis (*Graph 2.1*), intended as a predesign guide for Nicosia.

- a) The building is a residence with small internal heat gains amounting to 5800Wh/Day/person, the following were also assumed:
- b) The clothing has a level of 0.8 clo for winter and 0.4 clo for summer comfort.
- c) The activity level is taken as 1,3 Met, equivalent to slow walking or office work.
- d) The radiation figures to compensate for the successively low air temperatures are plotted for Cyprus for an average solar attitude of 52 degrees.
- e) An average day for each month of the year is plotted on the bioclimatic chart to be used for the analysis of the Cypriot climate. For this the average maximum temperature with the minimum relative humidity and



the average minimum temperature with the maximum relative humidity were plotted and connected by a line. This line represents approximately the change in temperature and humidity over that average day.

- f) To plot an average day of a month, although maximum and minimum temperatures do not occur in intervals of 12 hours in all seasons, it is assumed that the high temperature occurs at 4.00 pm and the low at 4.00 am.

### Concluded Predesign Strategies for Nicosia

From the bioclimatic chart analysis of maximum and minimum temperatures and corresponding relative humidities plotted for Nicosia, as explained above, the following strategies are concluded for the location's climate:

- The mechanical heating required to restore comfort seems to be restricted to the most acute winter days.
- Utilization of solar radiation, through out winter months, could provide comfort conditions in their duration, in well insulated buildings.
- Shading could be necessary from as early as April till the lingering hot days of October.
- High thermal mass combined with natural night ventilation, radiative, and evaporative cooling are sufficient means for providing comfort conditions through out the summer.
- Mechanical air conditioning is not needed for residential buildings.

Table : 2.2 3 Hourly Temperatures

J	F	M	A	M	J	J	A	S	O	N	D	
5.4	5.5	6.8	10.0	14.3	18.4	21.5	21.5	18.1	14.1	10.5	7.2	3
6.0	6.1	7.6	11.0	15.2	19.3	22.5	22.5	19.0	15.0	11.2	7.8	6
9.0	9.4	11.1	15.1	19.8	24.0	27.0	27.1	23.8	19.0	15.0	11.0	9
12.8	13.5	15.8	20.5	25.5	30.0	33.0	33.1	29.9	24.5	19.5	14.6	12
15.0	16.0	18.6	24.0	29.3	33.8	36.5	36.7	33.0	28.0	22.5	17.0	15
14.5	15.5	18.0	22.0	28.2	32.8	35.8	36.0	32.0	27.0	21.7	16.5	18
11.5	12.1	14.2	19.0	23.8	28.0	31.0	31.1	27.5	23.8	18.0	13.5	21
7.8	8.1	9.8	13.5	18.0	22.0	25.2	25.2	21.8	17.5	13.5	9.8	24



Transferring the analytical results from the bioclimatic chart to a timetable of a yearly grid (*Table 2.2*), where each square represents approximately 1% of the year and the values are assessed on a 3hourly basis, indicated on the vertical axis, the following breakdown of strategies as percentages are tabulated:

**Table : 2.3 Strategies for Nicosia**

STRATEGY	% of Year
MECHANICAL HEATING	2
PASSIVE SOLAR HEATING	51
SHADING	31
PASSIVE COOLING	16
AIR CONDITIONING	0
	100%

The above evaluation of the bioclimatic chart combined with the assessment of physiological comfort for Cyprus, based on a daily cycle (2.2.2: "**Climate and Physiological comfort in Cyprus**"), provide valuable predesign guide for the Cypriot House.



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## **CHAPTER 3**

# **METHODOLOGY AND MEANS FOR THE OPTIMIZATION STUDIES**



### **3.0 METHODOLOGY AND MEANS FOR THE OPTIMIZATION STUDIES**

#### **3.1 AIM**

The aim of this chapter is to define the house "Base-case" and the methodology and means of its optimization studies for the creation of a comfortable interior climate, using passive solar design to eliminate mechanical heating and cooling.

#### **3.2 APPROACH**

The approach for the optimization study is outlined as follows:

- (a) Establishing the house reference case for the optimization studies.
- (b) Defining the design variables and parameters to be tested.
- (c) Using micro-computer programs for building simulations and thermal calculations.

##### **3.2.1 Establishing the House Base-Case for Optimization**

###### **3.2.1.1 Concept and Objective**

The type of house envisaged to form the base-case is intended as the representative house of a middle to upper class average income family, which could appeal to the island's largest possible single group of population, who could afford such a house embodying as many characteristics of passive solar design as might be technically cost effective and inherently with the greatest potential for energy savings; such a house would present uprising tendency for central air-conditioning installations. The framework within which the profile of the house base-case is to be outlined is defined by:

- (a) Respect of traditional Cypriot architecture (*Ref: 3.12, 3.17, 3.21, 3.26*).
- (b) Response to current housing trends and demands (*Ref: 3.22, 3.27*).
- (c) Considerations of climatic and thermal aspects for Cyprus (*Ref: 3.19, 3.25*).

###### **3.2.1.2 Reference Sources and Assumptions for House Base-case**

Confining within the above defined framework, and in developing the design of house base-case, the following reference sources were used:

- (a) The "Typical Private House" specified by Government energy consultants in their 1985 survey (*Ref: 3.24*) acted as the basis of the house base-case
- (b) The Housing Statistics of the Republic of Cyprus (*Ref: 3.27*) were used to give indices and information on the current trends and tendencies in housing construction and in effect to determine modifications on the



- "Typical Private House" as concluded in paragraph (a) above.
- (c) Retrospection of Traditional Cypriot Architecture mostly recorded in bibliography (*Ref: 3.12, 3.17, 3.26*), was studied to pick up the threads of continuity before the modern movement reprieved its natural evolution.
  - (d) Solar and thermal design considerations concluded in "Prototype Solar House for Cyprus" (*Ref: 3.25 (i)*) were taken into account for the improvement of the typical house for energy efficiency.
- It is assumed that from the analysis of the above considered source references the concluded house design scheme fulfils the functional requirements of a typical Cypriot house on which to carry out the energy optimization studies.

### 3.2.1.3 Criteria In Developing the House Base-Case

The following parameters were considered in developing the house base-case, which is to be used as the reference building for the optimization studies.

- (a) Location
- (b) Type
- (c) Size
- (d) Shape
- (e) Layout
- (f) Components
- (g) Shading
- (h) Air-Conditioning
- (i) Cost

In establishing the reference house the potential of maximum collective energy savings for Cyprus was taken into account (**1.3.7 "Potential In Dwellings for Energy Savings and Improvement in Thermal Environment"**).

- (a) **Location: Nicosia**  
**Criteria**
  - (i) It accommodates the largest number of households (*see Table: 1.3.7*)
  - (ii) It contains the largest number of houses with central heating (*see table 1.3.8*)
  - (iii) It demands the largest amounts of heating and cooling energy consumption (*table: 1.3.9*)
- (b) **Type: Single-Family, Detached, Two-Storey House.**  
**Criteria**
  - (i) The selected type of house represents the most energy intensive category of residence in Cyprus (**3.2.1.1 "Concept and Objective"**)
  - (ii) Current statistics and Survey study on "Census on Housing" indicate construction trend with preference to houses of this type (*Table: 1.3.6 40% flat empty*)



- (iii) Yearly saving energy potential ( $> 2,5 \text{ t.o.e/Household}$  (ref: 3.27 (i))).
- (c) **Size: Total Area=175m<sup>2</sup>, Height=6.0m (2.85m/storey)**  
**Criteria**
  - (i) Housing Statistics 1986 for average area of houses [(Ref: 3.27 (ii), (iii))].
  - (ii) Regulations concerning minimum plot area, plot ratio, coverage area, and building height [(ref: 3.22 (iii), (iv))].
  - (iii) Projected yearly energy gains to be obtained through measures from this range of domestic buildings (ref: 3.24).
- (d) **Shape: Rectangular, Two storey, Elongated 17.5x5m Long axis E-W with glazed South facade, Compact East and West wall area, and with sloping roof.**  
**Criteria**
  - (i) Bioclimatic analysis and derived design strategies (graph 1:1 and 1:2, table:2.3).
  - (ii) Olgyays insolation studies (Ref:3.20).
  - (iii) Statistics on current trends indicate preference for two storey houses [(Ref: 3.27 (ii), (iii))].
  - (iv) Scale of the built environment resulting from zoning after the town Planning Law and Legislation [(Ref: 3.22(iv))].
  - (v) Traditional character (Ref: 3.21, 3.26).
  - (vi) Streets and buildings regulations concerning building height, division of land into plots, plot dimensions, plot ratio, and coverage [(Ref: 3.22 (iii))].
  - (vii) From concluded floor area [( see (c) Size Above )]
  - (xii) Layout limitations.  
 Other three shapes are examined in the optimization studies, the Square, P-shape and L-shape (Drawings 1-5 4.0 "Results and Analysis"). These shapes were concluded as the most predominant shapes in traditional architecture (Ref:3.21, 3.26).
- (e) **Layout: Three Bedrooms**  
**One Living room**  
**One Dayroom**  
**One Kitchen**  
**Auxiliary spaces**  
**Verandas and Balconies**  
**Criteria**
  - (i) Limitations arising from shape.
  - (ii) Function and use
  - (iii) Contemporary preference for this type of layout (Ref: 3.13 "Typical Private house" and from census of housing).
- (f) **Building Components**  
**Roof**
  - 150mm Concrete slab
  - 50mm Screed
  - Aluminium foil
  - U value =  $2.86 \text{ w/m}^2\text{k}$



- |                 |   |
|-----------------|---|
| <b>Ext-Wall</b> | <ul style="list-style-type: none"> <li>- 200mm Hollow Bricks</li> <li>- 20 mm Three layers cement/plaster internally</li> <li>- Painted white three coats internally</li> <li>- 25mm Three layers rendering externally</li> <li>- 2-4mm spayed cement/marble dust</li> <li>- U value = 1.43 w/m<sup>2</sup>k</li> </ul> |
| <b>Int-Wall</b> | <ul style="list-style-type: none"> <li>- 100mm Hollow Clay bricks</li> <li>- 20 mm three layers cement/plaster</li> <li>- Three coats white paint</li> </ul>  |
| <b>Bathroom</b> | <ul style="list-style-type: none"> <li>- Porcelain Tiles</li> </ul>   |
| <b>WC-Wall</b>  | <ul style="list-style-type: none"> <li>- Two layers cement/plaster</li> </ul>   |
| <b>Floor</b>    | <ul style="list-style-type: none"> <li>- Terrazzo Tiles (Hall, Living, Dining rooms)</li> <li>- Ceramic Tiles ( kitchen, Bathroom, WC )</li> <li>- Fitted Carpet 6.8mm ( Bedrooms )</li> <li>- U value = 3.6 w/m<sup>2</sup>k</li> </ul>  |
| <b>Windows</b>  | <ul style="list-style-type: none"> <li>- Single Glazing 4mm</li> <li>- Timber Frame</li> <li>- 30m<sup>2</sup> South Facing</li> <li>- 3.5m<sup>2</sup> North Facing</li> <li>- No Glazing on West and East sides</li> <li>- Timber Shutters</li> <li>- U value = 4.8 W/m<sup>2</sup>k</li> </ul>                       |
| <b>Doors</b>    | <ul style="list-style-type: none"> <li>- Timber Frame</li> </ul>  |
| <b>Entrance</b> | <ul style="list-style-type: none"> <li>- Panelled</li> </ul>  |
| <b>External</b> | <ul style="list-style-type: none"> <li>- Glazed (2.20 x 3.00 m)</li> </ul>  |
| <b>Internal</b> | <ul style="list-style-type: none"> <li>- Painted and varnished (2.20 x 0.90 m)</li> </ul>   |
- (g) Shading**
- |                       |       |
|-----------------------|-------|
| <b>Overhangs</b>      | -None |
| <b>Extended Walls</b> | -None |
- (h) Air-Conditioning**
- |                |   |
|----------------|---|
| <b>Heating</b> | - Central Heating (Oil Fired Boiler)      |
| <b>Cooling</b> | - Central Chiller and room fan-coil units |
- Criteria**
- (i) Typical Private House (*Ref: 3.13(ii)*)
  - (ii) Construction Statistics (*Ref: 3.27(iii)*)
  - (iii) Regulations on ventilation and day-lighting
  - (vi) Sun-Path ( *Graph Ref: 3.20* )
  - (v) Prototype Solar House for Cyprus (*Ref: 3.25(i)*)
- (i) Cost: CYP 45,000**
- Criteria**
- (i) Current prices for good quality construction (*Ref: 3.22 (i), (ii)*)
  - (ii) The price excludes the cost of central heating and that of devices and passive design characteristics.



### 3.2.1.4 Summary Description of House Base-case

(a)	Location	:Nicosia
(b)	Type	:Single Family, Detached, Two-Storey
(c)	Size	:Area = 175m <sup>2</sup> , Height = 6.0m
(d)	Shape	:Two-Storey, Rectangular
(e)	Layout	:Bedrooms Upstairs-Other rooms Downstairs
(f)	Components	:Roof :Concrete slab 200mm + Screed
		Walls :Brickwalls - Plastered -Painted External = 200mm Internal = 100mm
	Floor	:Concrete slab 200mm + Tiles
		Windows :Aluminium Frame - Single Glazed
		Doors :External = Aluminium
		Internal = Flush Timber
(g)	Shading	:None
(h)	Air-Conditioning	
		Heating :Central Heating - Oil Fired Boiler - Room Fan-coil units
		Cooling :Central Chiller - Cold Water Production - Room Fan-coil units
(i)	Cost	:CYP 45,000

### 3.2.2 The Simulations

#### Introduction

In the following pages the constant parameters, the variables and their effect on other input data in the building simulations are discussed. Their use as data-sets is outlined, examined and illustrated. Also the simulation models used for the optimization study are described.

#### 3.2.2.1 Fixed Parameters, Using Data-Sets for Simulations

The following parameters were kept constant throughout the simulations of the optimization studies:

- (a) Location
- (b) Type
- (c) Size
- (d) Layout
- (e) Air-Conditioning

#### (a) Location = Nicosia

Based on the location of Nicosia the following data-sets for the simulations are defined:



- (i) **Latitude** — 35.10 Degrees
- (ii) **Longitude** — 33.20 Degrees
- (iii) **Elevation** — 160m
- (iv) **Weather data** The weather data used for the simulations are those of Nicosia (Ref.3.19) except for the simulations carried out with SERIRES (3.2.2.4). For this model hourly data for a complete year are needed for:
  - Temperature
  - Radiation
  - Wind

Since not all required weather data are available in hourly values for Nicosia, weather data recorded in Iraklion are used for the simulations (Ref. 3.16). Iraklion is located on the same latitude as Nicosia and is situated on the island of Crete which has morphological characteristics resembling those of Cyprus. Furthermore from a comparative weather data study of the two locations it was concluded that the Iraklion weather data of an "example year" are similar to those of Nicosia's. As the actual weather that the building will be subjected to cannot be known in advance and the performance of the building for long term (annual) energy consumption, is investigated under likely or average weather condition ("example year" or "typical year") the Iraklion data could replace the Nicosia weather data in the simulations. As further confirmation of appropriate replacement of weather data extreme pattern of weather was tested in simulations by selecting from Iraklion data what could be nearer to the coldest day (January 16) and the hottest (July 19) for Nicosia.

Specifically the weather data of the two stations used for the simulations relate as follows:

- **Ambient Temperature**

The fluctuations of mean monthly Temperature for Nicosia in relation to Iraklion are outlined below for the four seasons:

- Winter** (Dec, Jan, Feb) - Mean Maximum 1 to 4°C lower  
Mean Minimum 1 to 4°C lower
- Spring** (Mar, Apr, May) - Mean Maximum 1 to 11°C higher  
Mean Minimum 1 to 5°C lower
- Summer** (Jun, Jul, Aug) - Mean Maximum 4 to 10°C higher  
Mean Minimum 1 to 4°C lower
- Autumn** (Sep, Oct, Nov) - Mean Maximum 6 to 7°C higher  
Mean Minimum 4 to 5°C lower

From weather data it is further noted that the mean daily Temperature for Winter as well as for Summer are very close amounting to 10.5°C for Winter and 26.0°C for Summer. This is explained by the bigger temperature fluctuations occurring in Nicosia which balance out the difference observed between the mean monthly maximum and minimum temperatures.

- **Radiation**

The bright sunshine average monthly duration is slightly longer throughout the year in Nicosia than Iraklion. However, the amounts of solar radiation (Global, Direct and Diffuse received on horizontal surfaces) in Nicosia are within the same range of values as Iraklion for both Winter



(325 to 371 mj/sm) and Summer months (880 to 970 mj/sm).

- **Winds**

The mean average wind speed throughout the year lies within the same maximum and minimum values ranging between 2 to 10 m/s. However is noted that in Iraklion the highest values of wind speed 5 to 10 m/s occur in Winter, whereas in Nicosia occur more frequently during the summer months (May, June, July, August).

The above outlined weather data differences are taken into considerations especially when selecting the day for the simulations of extreme weather conditions. Furthermore, when using other simulation programmes ("QUICK" and "AGRELEK") incorporating the Nicosia weather data the results of indoor temperatures are compared and it is found that they match (Tables 4.1.0 and 5.1.0).

- (v) **Ground Temperature**      The Ground Temperatures are entered as monthly schedule values derived from the formula:

$$\text{Text.gnd} = 7.173 + 0.339 \text{ Text.air (Ref:3.23)}$$

Where Text.gnd      =      mean monthly external ground temperature (1.2m deep)

Text.air      =      mean monthly external air temperature

- (vi) **Skyline Profile**      =      Clear:- A clear profile is adopted since the study carried out under ideal conditions

- (vii) **Ground Reflectance** =      Value of 0.3. Assuming grass around the house (Ref. 3.6, 3.14).

(b) **Type = Two Storey - Detached House**

This is taken as the most representative type of house as defined in the description of "Typical House" (3.2.1.3 "Criteria in Developing the House Base-Case"). A young family of five people is assumed to be residing in the house.

**Internal Gains:**      Schedules of internal gains, for Winter and Summer are defined. These are based on the occupancy pattern of a "typical" family in Cyprus (Tables: 3.2.1 and 3.2.2).

(c) **Size = 440 m<sup>3</sup> (Total Volume)**

The following values are assigned to input data related to the size of the house:

- (i) **Floor Area** = 175 m<sup>2</sup> ( 70-90m<sup>2</sup> on each floor. Certain fluctuations of the volume and floor area occur due to the shape variations).
- (ii) **Height** = 2.8 m ( Floor to ceiling)
- (iii) **Infiltration Rate** = 0.5 ac/h in winter and summer day 10-15ac/h in summer nights.



Under ideal conditions an airtight building is assumed with the value of 0.5 ac/h in winter. The same value is used for summer days when the hot air is undesired. During the summer nights however, when the air is cool and airflow is encouraged, the ventilation value is raised to 15 ac/h.

This value is possible for Nicosia climatic conditions and the building data (*Ref: 3.6 A4*).

**(d) Layout = Base-Case Outline**

The same criteria used in developing the layout of the "House Base-Case" are also employed in all shape variations (3.2.1.3 "Criteria in Developing the House Base-Case". Also see drawings 1-5 "Results Analysis").

**(e) Air-Conditioning (For 5000 Method & SERIRES)**

(i) **Capacity** = Adequate (as defined by the programme)

(ii) **Thermostat Settings**

5000 Method = 18.5°C

SERIRES = 19 degrees in winter and 26 degrees in summer, intermittently operated based on the daily life pattern of the inhabitants (1.3 "Energy Sources and Usage in House", 2.2.2 "Climate and Physiological Comfort in Cyprus").

### **3.2.2.2 Variables Varied Parameters - Using Data-sets**

Four main variables were tested in the simulations:

- A. **Shape**
- B. **Glazing**
- C. **Insulation**
- D. **Mass**

In the following pages the four main variables and their effect on other parameters in the building simulations are outlined and discussed.

#### **A. SHAPE**

Four main shape variations are employed in the study:

**Rectangular**

**Square**

**L-Shape**

**Π-Shape** (*Drawings: Appendix 3.3.0*)

The selection of the above shapes is based on the shape analysis of the Cypriot traditional architecture (*Ref:3.21,3.26*). These shapes are to be tested against the reference "Base-Case" (3.2.1 "Establishing the Cyprus House Base-Case for Optimization"). From these tests the most efficient shape is to be selected to proceed with other simulations for design optimization.



- **Rectangular Shape ( The Reference House, Base-Case)**

- (a) **Dimensions**

- (i) Width = 5m :- Minimum width necessary to accommodate rooms (3m room width + 1m Corridor), resulting from the area of each floor (3.2.1.3"Criteria and Considerations in Developing the House Base-Case").
- (ii) Length=17.5m :- Maximum allowable length determined by plot dimensions and siting regulations [(Ref:3.22 (iii), (iv))].

- (b) **Layout-Orientation**

- (i) Solar Gain :- All rooms have the potential to be South oriented to enjoy winter sun.
- (ii) Cold Protection:-Provided by buffering livable spaces with corridor and auxiliary rooms (Bathroom, store-rooms, w.c etc).
- (iii) Sun Protection:- Narrow East and West sides ensure avoidance of summer sun.

- (c) **Glazing**

- (i) Large south glazing area (60m<sup>2</sup>) for winter sun.
- (ii) Small North glazing area (3.5M<sup>2</sup>).

**Main Advantage :-** Utilization of winter sun, due to extensive south glazing area.

- **Square Shape**

- (a) **Dimensions**

- (i) Width = 9.35m :- Derived from the concluded floor area of the house "Base-Case" [(3.2.1.3, (c)Size)].

- (b) **Layout-Orientation**

- (i) Limitation of number of rooms.
- (ii) Limitations of orientation; not all rooms enjoy South winter sun.
- (iii) No cold buffering is possible.
- (iv) No privacy buffering is possible.

- (c) **Walls**

- (i) Large exposed East and West wall area unavoidable.
- (ii) Limited South wall.

- (d) **Glazing**

- (i) Limited maximum South glazing area (35m<sup>2</sup>).
- (ii) Limited extent of minimizing North glazing area. (4m<sup>2</sup>). Regulation requires 10% of the floor area of a living space for light and ventilation.
- (iii) Extensive East and West wall areas without glazing.
- (iv) West wall requires window for w.c ventilation.

**Main Advantage :-** Compactness of the shape.



- **L-Shape**

- (a) **Dimensions**

Basically the edge of the rectangular shape (4mx5m) is bent to form the L extension. The dimensions of the extension are determined by functional criteria.

- (i) Length = 4m.
    - (ii) Width - East side = 4.00m.
    - (iii) Width - West side = 8.00m

- (b) **Layout-Orientation**

- (i) South orientation for all the rooms.
    - (ii) North cold buffering with corridor, auxiliary rooms and staircase.
    - (iii) Formation of courtyard.

- (c) **Walls**

- (i) Extensive south walls.
    - (ii) East and west extensive walls (8.00m long).

- (d) **Glazing**

- (i) Extensive south glazing area (50.00m<sup>2</sup>).
    - (ii) Minimized North glazing area limited to 1.50m<sup>2</sup>.
    - (iii) No need for east or west openings.

**Main advantage :-** Formation of courtyard; sun blessed in winter, shaded in the summer.

- **Π-Shape**

- (a) **Dimensions**

The Π-shape is formed by bending the edges (3.00mX4.00m) of the basic rectangular shape house towards South.

- (i) Length = 14.00m (South and North walls)
    - (ii) Width = 6.00m (East and West walls).

- (b) **Layout-Orientation**

- (i) South orientation for all the rooms except the kitchen.
    - (ii) North buffering by corridor and auxiliary rooms as w.c, shower and bathroom.
    - (iii) Formation of south courtyard.

- (c) **Walls**

- (i) Extensive south wall (14.00m).
    - (ii) Extensive East and West walls (6.00m).

- (d) **Glazing**

- (i) Extensive South glazing area (50.00m<sup>2</sup>).
    - (ii) North glazing limited to 1.50m<sup>2</sup>.



- (iii) No East or West glazing needed.

#### **Main Advantages:**

- (i) South Glazing protected from east and west sun by the building extensions
- (ii) Formation of south facing courtyard.

### **B. GLAZING**

An area of 30.00m<sup>2</sup> south glazing is taken as the uniform basis for all shapes.

#### **(a) Maximum South Glazing Area**

On maximizing the south glazing area, limitations due to shape variations allow the following maximum glazing increase:

Rectangular	60.00 m <sup>2</sup>
Square	35.00 m <sup>2</sup>
L -Shape	50.00 m <sup>2</sup>
Π-Shape	50.00 m <sup>2</sup>

#### **(b) Minimum North Glazing Area**

In minimizing the north glazing area limitations due to the layout of the shape variations, allow the following glazing area decrease:

Rectangular	00.50 m <sup>2</sup>
Square	03.50 m <sup>2</sup>
L -Shape	01.75 m <sup>2</sup>
Π-Shape	02.00 m <sup>2</sup>

#### **(c) Glazing Type**

Glazing is to be tested in two variations:

- (i) Single Glazing.
- (ii) Double Glazing.

### **C. INSULATION**

The following aspects of insulation are to be tested in the building simulations:

- (a) **Thickness**
- (b) **Stage of Introduction**
- (c) **Position on the envelope**
- (d) **Extend**

#### **(a) Thickness**

Three different thicknesses of thermal insulation (polystyrene) are

- (i) 25mm
- (ii) 50mm
- 75mm

#### **(b) Stage of introduction**

Insulation is introduced in three different stages of the building:



- (i) On the unimproved "base-case" house
  - (ii) On thermally improved structure
  - (iii) On thermally optimized structure
- (c) Position on the envelope**  
Concerning the position on the envelope the insulation is examined as follows:
- (i) Internally
  - (ii) Sandwiched
  - (iii) Externally
- (d) Extend**  
As far as the extend of the insulation this is examined:
- (i) On the roof only
  - (ii) On the roof and walls
  - (iii) On the roof, walls and floor.

#### **D. MASS**

The effectiveness of mass increase is to be examined internally and externally.

- (a) Internally**
- (i) By replacing 100mm brickwall with 200mm brickwall.
  - (ii) By replacing 100mm brickwall with 100mm concrete.
- (b) Externally**
- (i) Replacing the 200mm external solid brickwall with 200mm concrete.
  - (ii) Replacing the 100mm external brickwall skin of cavity wall with 100mm concrete
  - (iii) Replacing the 100mm internal brickwall skin of cavity wall with 100mm concrete.

#### **3.2.2.3 Building Elements Affected by the Design Variables**

The building elements affected by the design variables are mainly the following:

- (i) Walls (internal, external)
- (ii) Floors (ground, upper)
- (iii) Roof
- (iv) Windows

The computer programme "Serires" which is employed for the building simulations, is particularly sensitive to the solar effects of the surfaces of the above elements and therefore to their orientation and sizing.

In the following pages the criteria for the sizing of these elements and the dimension alterations due to the house shape and glazing variations are discussed and tabulated.



### **Criteria in Sizing the Building Elements**

#### **Height of all Internal Walls and Surfaces**

- (i) Floor to ceiling 2.80m, is determined by Cyprus building regulations.
- (ii) South surface floor to overhang 2.00m is determined by the position of the overhang.

#### **Floor and Roof Area**

- (i) Ground and upper floor have the same area.
- (ii) The area of 175.00 square meters is taken for the reference house. This area varies according to the shape due mainly to the overhang extend (*table:3.1*)

#### **Length of Internal Walls**

- (i) The minimum extend of wall area needed for an open plan layout of kitchen, dining and living space, is taken for the ground level.
- (ii) For the upper floor also the minimum extend of walls needed for the privacy of each space is taken.

#### **Length of External Walls and Surfaces**

- (i) The maximum, allowed by the shape, length of south wall and surfaces is taken.
- (ii) For the east and west walls the minimum length is taken according to the shape.
- (iii) The length of the north wall is concluded by the shape in combination with the two previous criteria on wall length.

#### **Glazing**

- (i) An area of 30.00 square meters is taken as the basic glazing area for each shape, offering spacious openings to the south oriented rooms.
- (ii) East and west openings are avoided in all shapes except of 0.25m on the L-shape for ventilating the water closet.
- (iii) An area of 3.50 square meters is allocated on the north wall of all the shapes; this is the minimum area for lighting and ventilation required by the Cyprus regulations.











Table 3.3.0: BUILDING SIMULATIONS - ORDER AND DRAWINGS

DRAWING	SIMULATION	VARIABLE	DRAWING/ALTERATION	PREVIOUS SIMULATION
RECTANGULAR SHAPE				
RA	RA	Reference	Base-Case	NONE
RA	RAa	Insulation Envelope	25mm on Roof, Walls, Floor(Ext)*	RA
RA	RAb	Insulation Envelope	50mm on Roof, Walls, Floors (Ext)	RA
RA	RB	Infiltrat/Ventilat	NONE	RA
RA	RBb	Temperatures	NONE	RA
RA	RBa	Fenestration	Glazing Reorientation	RB
RA	RAc	Fenestration	Overhangs & Sidewalls	RA
RA	RBc	Infiltrat/ Ventilat	NONE	RA
RA	RC	Insulation/ Envelope	25mm on Roof, Walls, Floor (Ext)	RB
RA	RD	Temperature	NONE	RBc
RA	RE	Temperature	NONE	RBc
RA	RF	Temperature	NONE	RE
R1	R1	Fenestration/ shape	Glazing Reorientation	RA
R1	R1a	Infiltrat/ Ventilat	NONE	R1
R2	R2	Fenestration/ Area	Maximum South Glazing	R1
R2	R4	Mass/Walls	Internal Walls - Concrete	R2
R2	R5	Mass/Walls	External Walls Concrete	R4
R2	R6	Insulation	50mm on Roof & Walls	R4
R2	R6b	Insulation	40mm on Roof & Walls	R2
R2	R12	Insulation	50mm on Roof only	R4
R3	R3	Fenestration	Raised Overhang	R2
L-SHAPE				
L1	L1	Shape	Basic L-Shape	NONE
L2	L2	Fenestration	Maximum South Glazing	L1
L2	L4	Mass/walls	Internal Walls Concrete	L2
L2	L5	Mass/walls	External Walls Concrete	L4
L2	L6	Insulation	50mm on Roof and Walls	L4
L3	L3	Fenestration	Raised Overhang	L2
Π-SHAPE				
Π1	Π1	Shape	Basic Π-Shape	NONE
Π2	Π2	Fenestration	Maximum South Glazing	Π1
Π2	Π4	Mass/Walls	Internal Walls - Concrete	Π2
Π2	Π5	Mass/Walls	External Walls - Concrete	Π4
Π2	Π6	Insulation	+ 50mm on Roof & Walls	Π4
Π3	Π3	Fenestration	Raised Overhang	Π2



SQUARE SHAPE				
S1	S1	Shape	Basic Square Shape	NONE
S2	S2	Fenestration	Maximum South Glazing	S1
S2	S4	Mass/Walls	Internal Walls-Concrete	S2
S2	S5	Mass/Walls	External Walls-Concrete	S4
S2	S6	Insulation	+50mm on Roof & Walls	S4
S2	S8	Insulation	Sandwiched in Cavity Wall	S6
S2	S9	Mass/Walls	Internal Cavity Skin-Concrete	S8
S2	S10	Insulation	+50mm on ground floor	S6
S2	S11	Glazing Type	NONE	S6
S2	S12	Insulation	50mm on Roof only	S4
S2	S13	Mass/Walls	Internal Walls 200mm BWK	S11
S2	S14	Ventilation	NONE	S11
S2	S15	Ventilation	NONE	S13
S2	S17	Mass/Walls	+10m <sup>2</sup> Internal Brickwall	S15
S2	S19	Mass/Wall	+External BKW Skin	S15
S2	S20	Insulation/Roof	50mm Roof only	S15
S2	S21	Air -conditioning	NONE	S15
S3	S3	Fenestration	Raised Overhang	S2
S16	S16	Fenestration	+3.5m <sup>2</sup> North Glazing	S15
S18	S18	Roof Construction	+ Roof Tiles	S15

- NOTES:
- (a)For further information see 4.1 The Results of Parametric Studies and Tables: 4.1.1 - 4.1.5

(b)The main building Drawings are illustrated in Appendix 3.30

(c)\*Ext = Externally

(d)+ = Addition

(e)Infiltrat/Ventilat = Infiltration/ventilation



Table 3.2.1: SCHEDULE OF WINTER INTERNAL GAINS (In Watts)

GROUND FLOOR						FIRST FLOOR			
HOUR	PEOPLE +	LIGHTS-TV WASHING	COOKING	HEAT - LOSSES ++	SCHEDULE VALUE	PEOPLE	LIGHTS	CLEANING	SCHEDULE VALUE
1	0	0	0	50		300	0	0	
2	0	0	0	50		300	0	0	
3	1* 0	0	0	50	50	1* 300	0	0	300
4	0	0	0	50		300	0	0	
5	0	0	0	50		300	0	0	
6	0	0	0	50		300	0	0	
7	2* 250	250	500	50		2* 250	250	0	500
8	250	250	500	50	1100	250	250	0	
9	100	1000	0	50		50	0	100	
10	3* 100	1000	0	50		50	0	100	
11	100	0	0	50	150	50	0	100	
12	100	0	0	50		50	0	100	150
13	100	0	1000	50		50	0	100	
14	4* 500	500	0	50	1050	50	0	100	
15	500	500	0	50		50	0	100	
16	5* 200	0	0	50		50	0	100	
17	200	0	0	50	250	50	0	100	
18	200	0	0	50		50	0	100	
19	350	400	3000	50	3800	100	200	0	
20	350	400	3000	50		100	200	0	
21	200	400	0	50		100	200	0	300
22	200	400	0	50	650	100	200	0	
23	200	400	0	50		300	0	0	
24	200	400	0	50		300	0	0	

## NOTES:

+ One Adult = 100w - One Child = 50W

++ Heat Losses (Boiler and Hot Water)

1\* All Asleep

2\* All Active (Breakfast)

3\* Cleaner

4\* All Home (Lunch)

5\* Children (Dinner TV)



Table: 3.2.2: SCHEDULE OF SUMMER INTERNAL GAINS (Watts)

GROUND FLOOR						FIRST FLOOR		
HOUR	PEOPLE +	LIGHTS TV	COOKING CLEANING ++	TOTAL	SCHEDULE VALUE	PEOPLE	LIGHTS	SCHEDULE VALUE
1	0	0	0	0		300	0	
2	0	0	0	0		300	0	
3	1* 0	0	0	0	0	1* 300	0	
4	0	0	0	0		300	0	300
5	0	0	0	0		300	0	
6	0	0	0	0		300	0	
7	2* 250	0	200	450	750	2* 250	0	250
8	250	0	200	450		250	0	
9	100	0	1000	1100		50	0	
10	3* 100	0	0	100	100	50	0	
11	100	0	0	100		50	0	50
12	100	0	0	100		50	0	
13	100	0	1000	1100	750	50	0	
14	4* 400	0	0	400		50	0	
15	100	0	0	100		6* 250	0	250
16	100	0	0	100	100	250	0	
17	100	0	0	100		0	0	0
18	100	0	0	100		0	0	
19	100	0	0	100		0	0	
20	250	300	1000	1550		150	100	250
21	5* 250	300	0	550	750	150	100	
22	250	300	0	550		150	100	
23	0	0	0	0	0	300	0	300
24	0	0	0	0		300	0	

- NOTES:
- +One Adult = 100w, 1 child = 50w

++Light Cooking, Barbecue or Take Away

1\*All Asleep

2\*All Active (Breakfast)

3\*Cleaner

4\*All Home (Lunch)

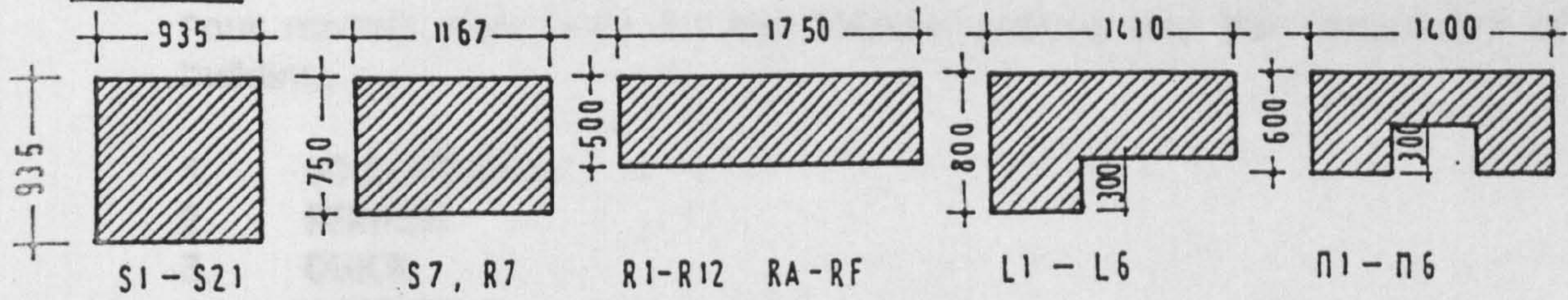
5\*Children (Dinner, TV)

6\*Siesta

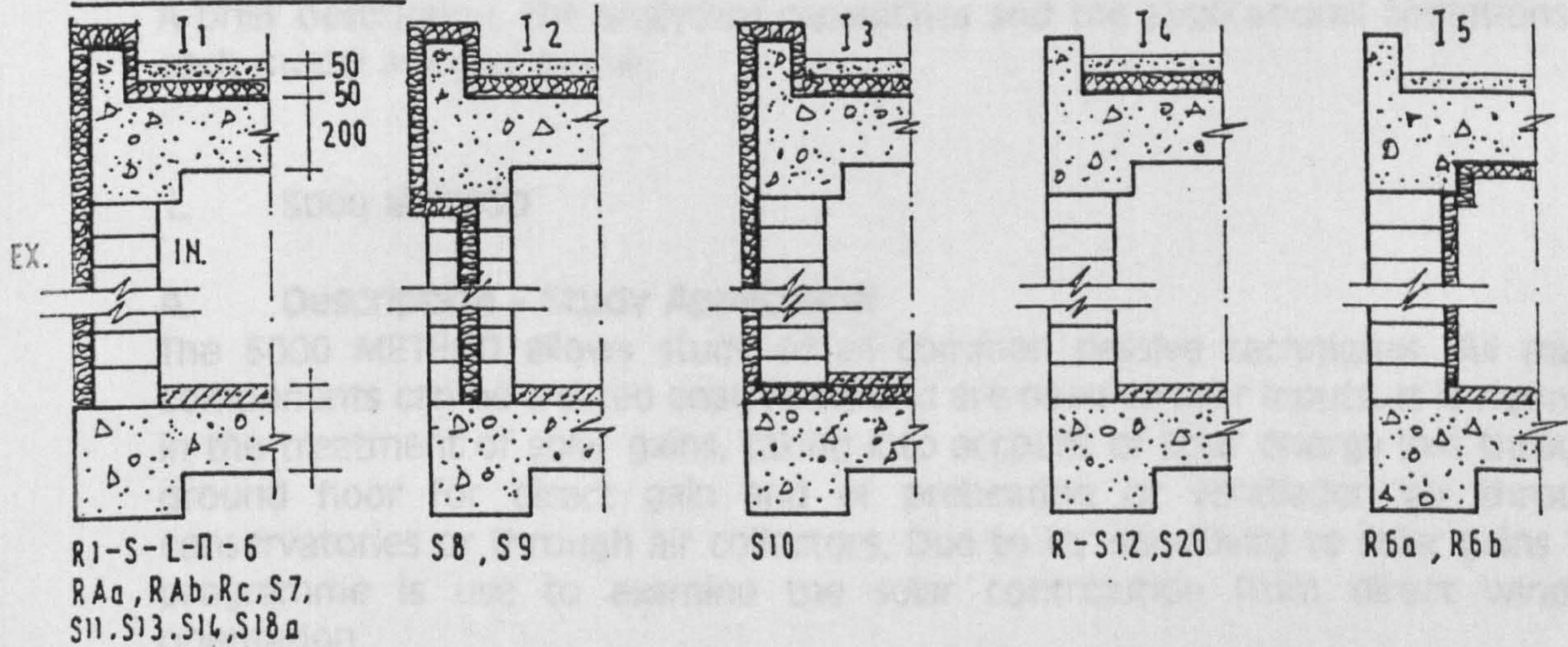


### Shedule 3.3.3: DRAWING VARIABLES FOR SIMULATIONS

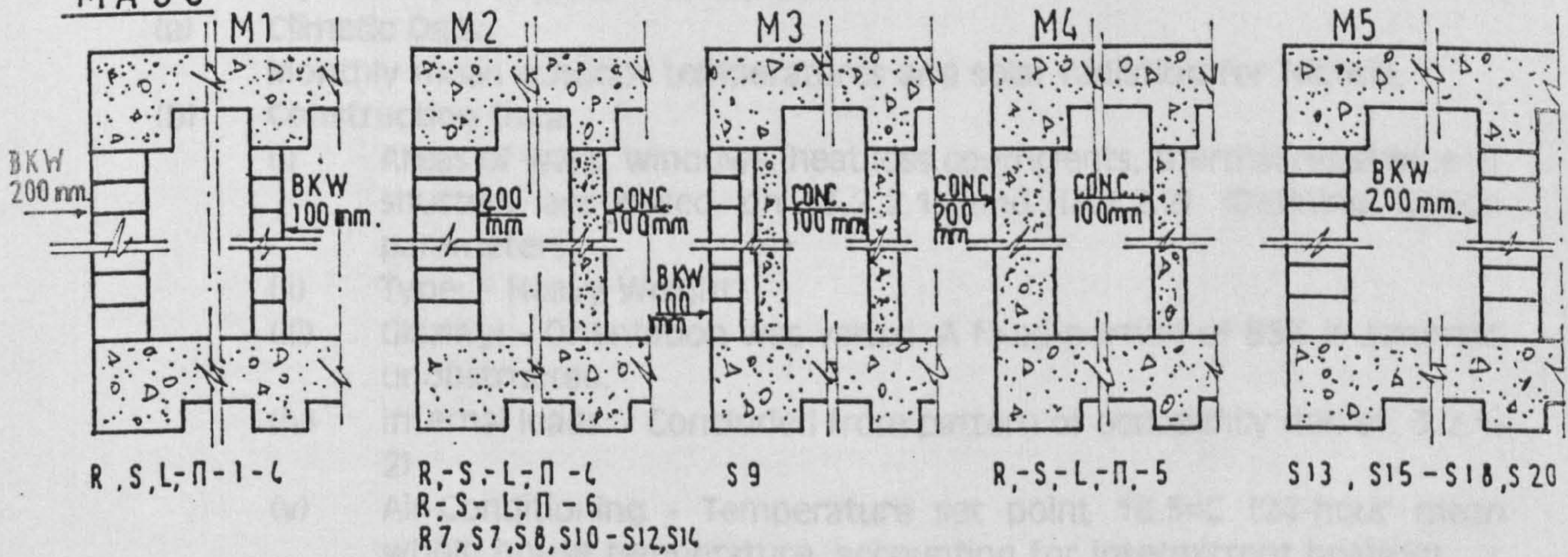
#### SHAPE



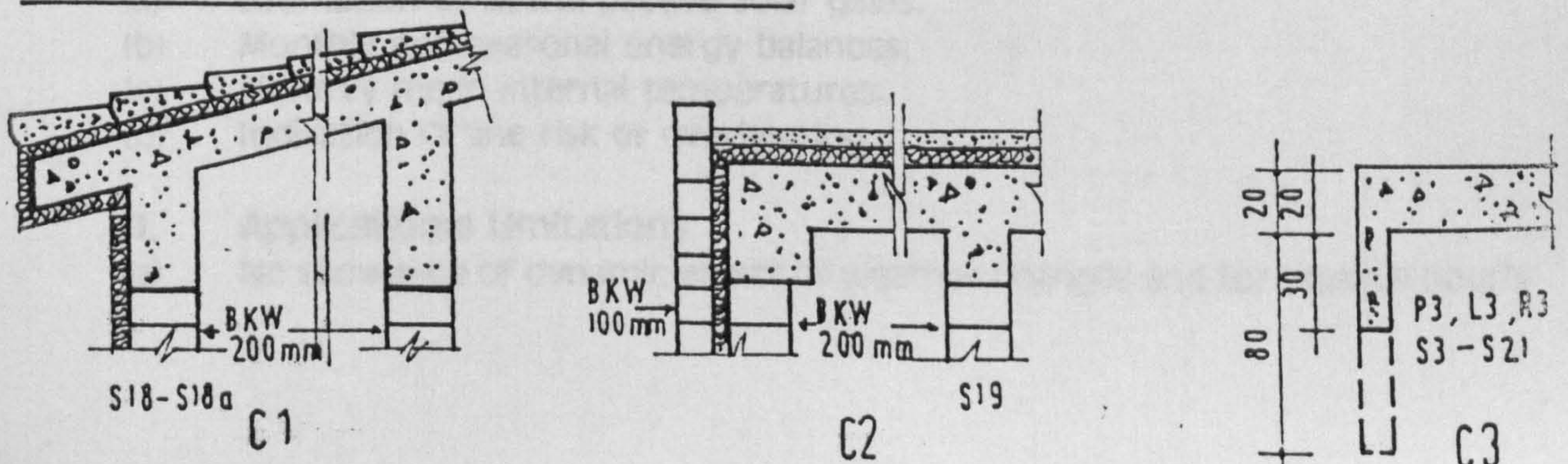
#### INSULATION



#### MASS



#### OTHER CONSTRUCTION DETAILS





### 3.2.2.4 The Simulation Models

Four models were used for the thermal analysis and the calculations of the building:

1. 5000 METHOD
2. SERIRES
3. QUICK
4. AGRELEK

A brief description, the analytical capabilities and the applicational limitations of each model are give below.

#### 1. 5000 METHOD

##### A. Description - Study Application

The 5000 METHOD allows study of all common passive techniques. All major components can be treated analytically and are open to user inputs. It is rigorous in the treatment of solar gains, taking into account of solar energy lost through ground floor for direct gain and of preheating of ventilation air through conservatories or through air collectors. Due to its' sensitivity to solar gains the programme is use to examine the solar contribution from direct window orientation.

##### B. Input Requirements - Study Data

###### (a) Climatic Data

Monthly mean outdoor temperatures and solar radiation for Nicosia.

###### (b) Construction Data

- (i) Areas of walls, windows, heat loss coefficients, thermal resistance of shutters are based on [3.2.2.1] and [3.2.2.2] (Defining design parameters).
- (ii) Type: - Heavy Weight
- (iii) Glazing: - Orientation was varied. A fixed portion of 85% is assumed unobstructed.
- (iv) Internal loads: - Concluded from pattern of occupancy (tables: 3.2.1, 2)
- (v) Air-Conditioning - Temperature set point 18.5°C (24-hour mean whole house temperature, accounting for intermittent heating).

##### C. Output

- (a) Estimation of useful passive solar gains.
- (b) Monthly and seasonal energy balances.
- (c) Monthly mean internal temperatures.
- (d) Indication of the risk of overheating.

##### D. Applicational Limitations

- (a) No allowance of dynamic effect of weather changes and for internal hourly



- thermal storage.
- (b) No allowance for intermittent heating.
- (c) No allowance for cooling requirements.
- (d) Little information on internal comfort conditions especially outside the heating season.
- (e) Certain building parameters are constant and cannot be changed to accommodate different values.
- (f) Occupancy patterns are implicitly assumed at a fixed rate. No opening of windows is accounted for.

The above limitations are not expected to cause errors on the preliminary calculations for the building and windows orientation. However due to the limitations, for the optimization study a more detailed and dynamic program was used (SERIRES).

## **2. SERIRES**

### **A. Description - Study Applications**

It is primarily a building loads program, particularly suitable for the analysis of residential buildings. It is designed to simulate the dynamic performance of the building in great detail and report the amounts of energy and power that the heating and cooling must supply in order to maintain comfort conditions. The building is represented mathematically as a thermal network with non-linear, temperature dependent controls. The fundamental concept of the programme is that of heat flow paths of a structure and in terms of thermal zones. A zone is the space (a room or a group of rooms) that operates at the same temperature. Two zones are significant; that of the outdoor air (ambient) and a user defined temperature (ground). Conceptually a building is represented as one or more zones with thermal flow paths between one another and the outdoor temperature and solar radiation. The components of the building (walls, windows, etc.) and infiltration are considered as the thermal flow paths. The features of the components and their major heat flow elements must be specified. This is followed by detailed description of the layers that comprise the element and the properties of the materials that compose each layer. Furthermore, the description must include the orientation, size and shading of the exterior surfaces, equipment specification, schedules and all details that affect the heat flow elements. The programme offers the user great flexibility in choosing the level of details to be used in modelling a building. For the current study the model was used to evaluate various options and to perform detailed analysis of the zero energy house design.

### **B. Input Requirements - Study Data**

#### **(a) Climate Data - Location**

- (i) Station: Nicosia site except weather data (3.2.2.1 "Fixed Parameters Using Data -Sets for Simulations" (a) Location).
- (ii) Ground Reflectance - The value of 0.3 (assuming grass. Ref.:3.6,3.14).
- (iii) Ground Temperature - Monthly schedules [3.2.2.1 (a) Location]

#### **(b) Construction**

- (i) Zoning: Two zones (Ground and Upper)



- (ii) **Conduction Elements:** Treated as pure resistance and as composite elements with heat capacity. Values for detailed data are based on 3.2.2.0 "Defining Data and Design Parameters".
- (iii) **Exterior surfaces:** Campus, azimuth, tilt height and length are based on the defined design parameters (3.2.2.1 and 3.2.2.2).
- (iv) **Windows:** Glazing type, characteristics, dimensions, locations on the surface are entered as varied parameters.  
 Shading Coefficient - Scheduled for Winter and Summer  
 Solar fraction Lost - Value = 0.1  
 Solar Fraction to Air - Value = 0.2  
 Shading Elements - Horizontal overhangs and extended walls of projection.
- (c) **Internal Gains** Scheduled hourly (appliances and occupying) for Winter and Summer [3.2.2.1(c) Size (iii)].
- (d) **Infiltrations/Ventilation:** Scheduled hourly rates for Winter and Summer [3.2.2.1(c) Size (iii)].
- (e) **Equipment Air-Conditioning:**  
 Used in all simulations except Test S21 (under free running conditions).  
 Heating Set Point - 19°C between 06.00-09.00 and 16.00-23.00 hours.  
 Cooling Set Point - 26°C between 12.00-19.00 hours.  
 Venting Set Point - At 26°C.

## **C. Output**

### **(a) Energy Loads**

- (i) **Zones:** For two zones (ground and upper).
- (ii) **Period Season:** Monthly for a year and hourly for January 16 and June 19.
- (b) Temperatures**
- (i) **Zones:** For two zones and ambient
- (ii) **Period Season:** Mean monthly for a year and hourly for January 16 and June 19.

## **D. Applicational Limitations**

- (a) The shading of external surfaces and windows is not treated in full generality. It does not model the varied geometry of overhangs and extended walls or the varied extent of shading by shutters.
- (b) No allowance of natural ventilation through representative modelling of open window area.
- (c) No allowance of the evaluation of indoor thermal conditions through the varied design of shading and ventilation.

Since detailed analysis is necessary of the varied design of shading and ventilation and their effect on indoor thermal environment, under free running conditions the thermal analysis programme QUICK is used for the study of these variables.



### 3. QUICK

#### A. Description - Study Applications

It is a thermal analysis programme for evaluating the thermal performance of the building. The elements forming a building zone must be described by specifying the materials of their layers. The programme was used in the study to investigate the effect of occupants intervening on the operations of shading shutters and ventilation through the design of windows and their opening mode.

#### B. Input Requirements - Study Data

##### (a) Climatic data:

Hourly values of temperature, relative humidity, radiation (global and diffuse) for hot and cold design day for Nicosia.

##### (b) Construction:

(i) Zones: The house was defined as one zone

(ii) Zone Elements: Specifications and dimensions are based on information given in 3.2.1 "Establishing the House "Base-case" for Optimization and 3.2.2.1 "Defining Design Parameters".

(iii) Shading: The geometry of shading devices given in detail.

(c) Internal Gains: Values for diverse types of activities based on tables: 3.2.1 and 3.2.2 (schedules of internal gains)

(d) Infiltration/Ventilation: Variable hourly rates for summer and winter.

(e) Air-Conditioning: No air conditioning was used.

#### C. Output

(i) Prediction of hourly indoor air temperatures.

(ii) Prediction of heating and cooling loads (not for the current study).

#### D. Applicational Limitations

(i) Ventilation is entered as variable rates. Its effects on the thermal performance of the building was not modelled in detail through opening and closing of windows.

(ii) There are other limitations of the model which however do not effect the sensitivity of the results for shading operation.

For the modelling of the variable of ventilation an advance version of QUICK was employed, "AGRELEK".

### 4. AGRELEK

#### A. Description - Study Application

This program is a development of the thermal analysis programme "QUICK" version 4 with additional new features on occupancy and ventilation. The programme is employed in the study for its potential to calculate the natural ventilation rate accurately. This is defined as intentional airflow through purpose provided openings. It is calculated with a detailed numerical analysis procedure given the window particulars (dimensions, level e.t.c.).



**B. Input Requirements - Study Data**

- (a) **Building Type:** "Standard" (to agree with the specified one in the manual).
- (b) **Construction:** As in 'QUICK'.
- (c) **Fenestration:**
  - (i) Area, height and level of windows of varying opening mode.
  - (ii) Durations of opening mode: Three different ventilation periods, defined during the 24-hour day.

**C. Output**

- (i) Predictions of hourly indoor air temperatures.
- (ii) Predictions of heating and cooling loads (not for the current study).

**D. Applicational Limitations**

- (i) The ventilation prediction model is only stack driven. The wind effect (speed and direction) is ignored.
- (ii) Orientation of the open area is not accounted for.
- (iii) Relation of open window areas (adjacent opposite) is ignored.
- (iv) The infiltration model depends on different parameters than ventilation (infiltration depends on difference between inside and outside temperature; ventilation depends on open window area and difference of height). This causes inconsistent results when switching between ventilation model and infiltration model.

The above limitations are accounted for in the conclusions drawn from comparative studies as the results (5.2 "Ventilation").



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# **CHAPTER 4**

## **OPTIMIZATION RESULTS AND ANALYSIS**



## 4.0 OPTIMIZATION RESULTS AND ANALYSIS

This chapter presents the results and comparative studies of energy consumption in modified building design on the "Cyprus House". It explains the procedure for the performance of a zero energy building and analyses data which express the sensitivity of the annual energy consumption to selected parameters. Finally, it concludes on their effectiveness towards a zero energy house.

### 4.1 THE RESULTS

#### 4.1.1 Approach

The optimization results are computer calculations of building simulations carried out by computer program SERIRES (3.2.2.4 "The Simulation Models"). The computer building simulations developed from the house "Base-case" (3.2.1 "Establishing the House Base-Case for Optimization"), with the introduction of varied parameters as defined in 3.2.2.2 ("Variables, varied parameters, using data-sets"). The house "Base-Case" specifies the "Reference" values and are described in test no: RA. In the optimization process for "Zero Energy House", only one parameter is varied in the given set of data of each test while the others are held fixed at their reference values. The computations calculate monthly auxiliary heating requirements when indoor temperature falls below the specified thermostat setting, or the cooling demand if the temperature exceeds the specified upper limit. The sum of the monthly auxiliary heating and cooling load demand, amounts to the annual useful energy requirements for that test profile. Depending on the total annual energy requirement figure, the most effective parameters that minimize the energy load are employed in the process, while the others are either deployed or further investigated. The parametric optimization study continues till the minimum energy consumption nearing zero is reached by a simulation. This is regarded as the most economical and is defined as the zero energy simulation profile (Test no:S15). In order to confirm that the concluded "Zero Energy" profile achieves indoor comfort conditions without the need of mechanical heating or cooling a further test was carried out. In this test (S21) the simulation of the "Zero Energy" profile was computed under free running conditions (no auxiliary energy incorporated). The indoor, hourly temperatures were recorded (Table 4.1.0) for a cold and a hot day to examine possible deviation from comfort range.

#### 4.1.2 Classification

For the comparative parametric studies the simulations are classified in three major ranges as follows:

RANGE A - Test nos: RA-RF

RANGE B - Test nos: R1-R6, L1-L6, П1-П6, S1-S6

RANGE C - Test nos: R1a to R6a, R6b, R7, R12, S1 to S21



In presenting the results, each range of simulations is examined as an entity and invites general remarks derived from the tests it houses. This is followed by the description of the individual tests and remarks from comparative studies within the context of the range. In all ranges the analysis is performed on the basis of comparing the results of each test to the reference design of the "Typical House" (test no: RA). The objectives of each range as well as those of the tests within the range are outlined. The main observations of the tests are expressed in the form of remarks and the adopted effective parameters are concluded. A brief description of each test and the results of energy consumption (useful energy) and its cost, are outlined and calculated in Summary Results on tables 4.1.1 to 4.1.5.

#### 4.1.3 Parametric Studies - Objectives, Remarks, Conclusions

##### **RANGE A - Test nos: RA - RF**

**Range Objective:** To conclude to constant parameters, in order to serve as uniform basis for subsequent simulations. The tests are carried out on the "Typical Cypriot House" as defined in clause 3.2.1.4. (The summary results of the range are tabulated on Table:4.1.1).

##### **Test no: RA**

**Test Objective:** To establish "Base-Case" through studies of energy consumption.

**Remarks:** The results on energy consumption compare well with those concluded from the survey carried out by government energy consultants (Ref: 3.24 "Energy in Cyprus").

**Conclusion:** The house profile outlined in test RA forms the "Base-Case" for subsequent tests.

##### **Test nos: RAc, RBa, RBc**

**Test Objective:** To study the effect of varied design of glazing area, re-orientation, extended walls and overhang on Base-case.

**Remarks:** The re-orientation of windows and the introduction of extended walls and overhangs, considerably reduce the energy consumption in all three tests.

**Conclusion:** Adoption of re-orientation of glazing and introduction of extended walls and overhangs.

##### **Test nos: RAa, RAb, RC**

**Test Objective:** To study the effect of insulation of varied thickness on different building designs within the above range.

**Remarks:** The introduction of insulation contributes to energy reduction (38% reduction in test RC in comparison to test RBC). The more improved the design



is the more the incurring energy savings.

**Conclusion:** Addition of insulation to be adopted in the simulations at an improved stage of design.

<b>Test nos: RBb, RD, RE, RF</b>
----------------------------------

**Test Objective:** To investigate the effect of continuous and intermittent use of heating and cooling equipment, set at different hours and temperature. To compare with comfort conditions established in chapter 2.2 "Physiological Comfort in the Cypriot House".

**Remarks:** Operating heating and cooling equipment intermittently in order to be in accordance to the demands of a typical dwelling in Cyprus, as well as setting thermostat at temperatures established as "comfort conditions" (2.2.2 "Climate and Physiological Comfort in Cyprus"), result to considerable energy savings.

**Conclusion:** Space heating and cooling equipment to be set at 19 degrees Celsius for winter from 06.00 to 09.00 and 16.00 to 24.00 hours, and 26 degrees Celsius for summer from 12.00 to 19.00 hours.

<b>Test Nos: RB</b>
---------------------

**Test Objective:** To compare usual Infiltration rate in houses (3ac/h, no airtightness, no controlled use of openings) with that achieved by airtight design and effective use of openings, considering natural air flow patterns.

**Remarks:** Controlled infiltration Rate restricts considerably the energy load.

**Conclusion:** The value of 0.5 ac/h (a possible value of infiltration rate when good airtight building design is employed), to be adopted for consequent tests in winter days and nights and for summer days. The value of 10 ac/h is taken for summer nights infiltration rate, in tests R, L, P, S1 - 6, and S6 - S13 except in R1a in which infiltration rate of 15 ac/h (a possible value see 3.2.2 "Defining Variables and Parameters") responded effectively in reducing energy consumption in cooling. Hence the value of 15 ac/h was adopted in tests Nos: R1a S14 - S21.

<b>Conclusive Remarks for RANGE-A Tests</b>
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The concluded parameters to form the uniform basis for the subsequent simulations are:

**Glazing:** Orientation - North = 3.50m<sup>2</sup>, East/West-No Glazing, South = 30.00m<sup>2</sup>

**Shading:** Side vertical extended walls and horizontal overhangs (1m projection).

**Cooling and Heating Equipment:** To operate intermittently according to the demands of the typical Cypriot house Heating: 06.00 to 09.00, 16.00 to 24.00 at 19 degrees Celsius Cooling: 12.00 to 19.00 at 26 degrees Celsius (the temperatures are those derived from studies on "Comfort criteria" for the Cyprus house (2.2 "Physiological Comfort in the Cypriot House").



**Infiltration Rate:** The value of 0.5 ac/h to be employed when prevention of air flow intended, as in Winter (day and night) and during the Summer days. In Summer nights when air flow is desired the infiltration Rate value is raised to 10 ac/h an achievable number of air changes in the Cypriot house (5.2.2 "Defining design Variables").

<b>RANGE B - Test Nos: R1-R6, L1-L6, Π1-Π6, S1-S6</b>
---

**Range Objective:** To test major parameters of the main variables (Glazing, Mass, Insulation) on the four basic shapes (Rectangular, L-shape, II-Shape and Square), in order to employ the most effective ones in conjunction to the selection of the most energy efficient shape for further optimization studies. (The summary results of the range are tabulated on Tables:4.1.2 to 4.1.5).

<b>Test Nos: R1, L1, Π1, S1</b>
---------------------------------

**Test Objective:** To compare the four basic shapes with fixed parameters as concluded from Range A tests.

**Remarks:** The square shape presents the lowest energy consumption.

**Conclusion:** Although the "Square House" is found to be the most economic shape, the other three shapes were also further tested to investigate the possibility of different results when introducing other parameters.

<b>Test Nos: R2, L2, Π2, S2</b>
---------------------------------

**Test Objective:** To study the effect on the energy load when maximizing south glazing and minimizing North.

**Remarks:** This variation decreases the heating load but increases the cooling load totalling in price the result of the preceding tests (R1, L1, Π1, S1). However, the same glazing parameter in combination with the 50cm rise of overhang (R3, L3, Π3, S3) and mass introduction internally (R4, L4, Π4, S4) causes both heating and cooling load reduction.

**Conclusion:** The South increase and North decrease of glazing area to be used throughout consequent simulations (except in test S16 in which increase of north glazing is tested).

<b>Test Nos: R3, L3, Π3, S3</b>
---------------------------------

**Test Objective:** To study the effect on energy load when increasing glazing area exposure, by raising overhang.

**Remarks:** This measure increases solar gains in all different shapes, and therefore reduces heating load. The cooling load remains unaffected except in test R3 in which the load increases; possibly due to the larger glazing area.



**Conclusion:** The cooling load increase, noted above, implies the necessity of further tests on this parameter before reaching its optimization. Therefore the south glazing overhang as designed originally from solar data is to be employed in the proceeding tests.

**Test No: R4, L4, Π4, S4**

**Test Objective:** To test effect on energy load when increasing mass internally by replacing the 100mm brickwalls by 100mm concrete walls.

**Remarks:** In all tests, heating load decreases. Except in L4 which remains unaltered. In test Π4 the cooling load also decreases.

**Conclusion:** The increase of internal mass to be adopted in all consequent tests by replacing the internal Brickwalls by concrete walls (except in S13).

**Test Nos: R5, L5, Π5, S5**

**Test Objective:** To test effect of mass externally by replacing the 200mm external brickwalls by 200mm concrete walls.

**Remarks:** This variation causes increase in both heating and cooling load in all four different house-shapes.

**Conclusion:** The 200mm brickwall, typically used in Cyprus, to be used as the basic structure of external walls in the tests to follow.

**Test Nos: R6, L6, Π6, S6**

**Objective:** To test the effect of 50mm Polystyrene introduced on the building envelope.

**Remarks:** The introduction of insulation reduces considerably both the heating and cooling load in all four different shapes.

**Conclusion:** Insulation to be added in subsequent tests. Its position in combination with varied building design to be further investigated.

**Conclusive Remarks for RANGE-B Tests**

In all the above test (R, L, Π, S1-6) the square shape responded most effectively and thus was selected to conclude the optimization studies. However, two more tests (R7 and R12) on the rectangular house - were carried out for comparative studies with test Nos: S7 and S12. This deemed necessary since the rectangular shape performed second best results in the above tests, and introduction of new parameters might have brought it in the first position.



<b>RANGE C - Test Nos: R1a, R6b, R7, R12, S7 - S21</b>
--

**Range Objective:** To minimize energy consumption nearing zero point, through further parametric studies of the variables on the square house (concluded as the most energy efficient shape). The parameters of insulation, infiltration and dimensions were also tested on the Rectangular shape (Test nos: R1a, R6a, R6b, R7, R12). This exercise was carried out in order to ensure that the effect of these parameters does not alter the conclusions, regarding the square shape efficiency, reached in the previous range of tests. (The summary results of the range are tabulated on Tables:4.1.2 and 4.1.5).

<b>Test No: R1a</b>
---------------------

**Test Objective:** To investigate the effect of Infiltration Rate increase during summer nights.

**Remarks:** The increase of Infiltration Rate from 10 ac/h to 15 ac/h in summer nights reduces considerably the cooling load.

**Conclusion:** The value of 15 ac/h in summer nights, was adopted from test S13.

<b>Test Nos: R6a, R6b, S8, S10, S12, S20</b>
--

**Test Objective:** To study the effect of varied thickness, of the insulation its extent on the envelope, as well as the order of its application in terms and in combination with other materials.

**Remarks:** Application of the insulation on the outface of the envelope compares equally well with sandwiched insulation in cavity wall (S6, S8) whereas energy loading increases when applied on the internal side (R6, R6a). When decreasing thickness of insulation (R6a, R6b) the heating and cooling load increase. Restricting the insulation on the Roof only (compare S20 and S15, S12, S6, R12 and R6) increases energy load. Extending insulation on the floor slab results to greater energy consumption; (compare S6 and S10). This is caused mainly by the cooling load increase.

**Conclusion:** Application of 50mm Polystyrene, of resistance value  $R=1.22\text{m}^2\text{K/W}$ , externally on the envelope of the building are derived as the most effective insulation parameters.

<b>Test Nos: R7, S7</b>
-------------------------

**Test Objective:** To investigate two shape variations of Rectangular and square houses by introducing test no: R7 nearing the Rectangular house dimensions and test no: S7 nearing the square ones.

**Remarks:** The results amount to the same energy load from both shape variations; however this is larger than the load from the square shape.

**Conclusion:** The above shape tests confirm the shape efficiency of the square house.



**Test No: S9 (compared with S6, S8)**

**Test Objective:** To study the effect of additional mass on external cavity wall by replacing its inner, brickwork skin of 100mm (test No: S8) by 100mm concrete wall.

**Remarks:** The total energy load is the same:

**Conclusion:** The solid wall of 200mm BKW with insulation externally is taken as the basis for the consequent tests.

**Test No: S11**

**Test Objective:** To compare energy load when all single glazing is replaced by double glazing.

**Remarks:** Double glazing restricts energy load. Heating load decreases more than cooling.

**Conclusion:** Double glazing is introduced for the consequent tests.

**Test No: S13**

**Test Objective:** To compare effectiveness of mass on internal wall, when the 100mm concrete is replaced by 200mm BKW.

**Remarks:** The concluded energy load is the same in both tests.

**Conclusion:** The brickwork wall construction is to be adopted as this is typically used in Cyprus.

**Test Nos: S14, S15**

**Test Objective:** To test air ventilation Rate increase on square house shape.

**Remarks:** As in the case of Rectangular shape (test No: R1a), ventilation rate increase from 10 ac/h to 15 ac/h in summer night, causes cooling load decrease.

**Conclusion:** The value of 15 ac/h ventilation rate is used for summer nights. This value is achieved through the use of openings.

**Test No: S16**

**Test Objective:** To study the effect on energy load when the north glazing area is increased.

**Remarks:** Although the glazing increase is of limited area (3.5m<sup>2</sup>), how ever it can be observed that both heating and cooling load increase.

**Conclusion:** Minimum north glazing area to be employed in the tests.

**Test No: S17**

**Test Objective:** To study the effect of mass increase internally by adding 10m<sup>2</sup>



of internal brickwall.  
**Remarks:** Although in previous tests (R, L, Π, S-4) mass introduction internally has a positive effect in energy saving further internal mass increase leaves loading unaffected.  
**Conclusion:** The internal wall area as designed originally is used throughout the tests.

**Test No: S18**

**Test Objective:** To compare the tiled pitched roof with the flat concrete slab one.  
**Remarks:** The thermal resistance of the tiles acts as an energy load decreasing factor.  
**Conclusion:** Roof tiles to be introduced in the building.

**Test No: S19**

**Test Objective:** To compare external wall construction when adding a 100mm brickwall external skin (test no: S19) to that without it (S15).  
**Remarks:** The additional skin of brickwall decreased the energy load for heating cooling.  
**Conclusion:** The 200mm brickwall and 100mm brickwall outer skin with insulation in the cavity to be taken as the external wall construction.

**Test No: S21**

**Test Objective:** To study Indoor temperatures when no heating and cooling equipment is operating in a house in which the concluded effective parameters are employed. The profile of this simulation is outlined in 4.1.4 "Conclusions of Parametric Studies".  
**Remarks:** The indoor temperatures are the same as those achieved when heating and cooling equipment is in use (Table 4.1.0).  
**Conclusion:** The matching of indoor temperatures in free running house with those set with heating and Cooling equipment operation confirms the efficiency of the employed parameters.

**Conclusive Remarks for RANGE-C Tests**

Concluded Energy efficient parameters are:

- Infiltration Rate:** The value of 0.5 ac/h in Winter and 15 ac/h in Summer night.
- Insulation:** Polystyrene 50mm to be applied on walls and Roof.
- Glazing:** Double glazing to replace all single glazing.
- Mass:** Introduced internally by replacing the typical internal Cyprus



- wall construction of 100mm brickwork with 200mm brickwork.
- Tiles: Applications of tiles on the roof.
- Walls: External wall to be cavity with insulation and brickwalls of 200mm inner skin and 100mm outer skin.

4.1.4 Conclusive Parameters for Zero Energy Simulation Profile

The concluded effective parameters derived from the simulations (RANGES A, B, C 4.1.3 "Parametric Studies - Objectives, Remarks, Conclusions") were incorporated in the building simulation test no: S15 ("Optimization Results" and Table 4.1.5 "Summary results") and resulted to zero energy loading for space heating and cooling. The house design data, for zero space heating and cooling energy, was further tested in a building simulation (*Test no: S21*) without auxiliary energy and the temperatures were observed under free response of the building. The values of the resulted temperatures (Table 4.1.0) were lying within those defined for comfort conditions in Cyprus. This confirmed the validity of the concluded building simulation for "Zero energy " load for heating and cooling. The outline of construction characteristics of Zero Energy simulation profile is concluded as follows:

- Shape : Square
- Volume: 400 cubic meters.
- Area : 175 square meters.
- Walls : External – 20mm plaster (rendering)  
50mm polystyrene (insulation)  
200mm brickwalls  
20mm plaster (internal finishing)  
Internal – 20mm plaster (finishing)  
200mm brickwalls  
20mm plaster (finishing)
- Roof : 50mm Screed  
50mm polystyrene (thermal insulation)  
200mm concrete slab  
20mm plaster (ceiling finishing)
- Floor : Mosaic Tiles  
50mm Screed  
200mm concrete slab  
Ground
- Windows: Area – South = 35.00 sq.meters  
North = 3.50 sq.meters  
East = 0.00 sq. meters  
West = 0.00 sq. meters  
Type – All double glazing  
Shading – Overhangs, extended walls and shutters



Infiltration Rate	– Winter	=	0.5 ac/h throughout day/night
	– Summer	=	0.5 ac/h throughout day 15 ac/h throughout night
Temperature Hours	– Winter	=	19 deg.c 06.00-09.00, 16.00-24.00
	– Summer	=	26 deg.c 12.00-19.00 Hours



**Table 4.1.0            TEMPERATURES FOR A COLD AND A HOT DAY  
FROM ZERO ENERGY BUILDING SIMULATION (Test No: S15)  
(NO AUXILIARY HEATING AND COOLING LOAD.**

TEMPERATURES FOR JANUARY 16 °C					TEMPERATURES FOR JUNE 19 °C			
HOUR	INDOOR TEMPERATURE			OUTDOOR	INDOOR TEMPERATURE			OUTDOOR
	MEAN	MIN	MAX	MEAN	MEAN	MIN	MAX	MEAN
1	19.56	19.5	19.6	6.0	26.95	26.9	27.0	27.0
2	19.47	19.4	19.5	6.0	28.21	28.1	28.3	30.0
3	19.39	19.3	19.4	6.0	28.35	28.3	28.4	30.0
4	19.30	19.3	19.3	6.0	26.65	26.6	26.8	26.0
5	19.21.	19.2	19.2	6.0	26.51	26.5	26.6	26.0
6	19.12	19.1	19.2	6.0	26.43	26.4	26.5	26.0
7	19.09	19.1	19.1	5.0	26.16	26.1	26.2	25.0
8	19.06	19.0	19.1	6.0	27.07	27.0	27.1	27.0
9	18.86	18.8	18.9	6.0	27.20	27.2	27.2	27.0
10	19.13	19.1	19.2	8.0	26.90	26.9	26.9	27.0
11	19.34	19.3	19.4	8.0	26.88	26.9	26.9	27.0
12	19.75	19.6	19.9	11.0	26.98	27.0	27.0	29.0
13	19.93	19.8	20.0	10.0	27.38	27.3	27.4	28.0
14	20.06	20.0	20.1	10.0	27.47	27.4	27.5	28.0
15	20.14	20.1	20.2	11.0	26.82	26.8	26.9	26.0
16	20.13	20.1	20.1	12.0	26.75	26.7	26.8	26.0
17	19.95	19.9	20.0	12.0	26.91	26.9	26.9	27.0
18	19.69	19.6	19.8	11.0	26.70	26.7	26.7	26.0
19	19.65	19.6	19.7	11.0	26.65	26.6	26.7	26.0
20	19.55	19.5	19.6	10.0	26.14	26.1	26.2	25.0
21	19.45	19.4	19.5	9.0	26.07	26.0	26.1	25.0
22	19.38	19.4	19.4	8.5	25.73	25.7	25.8	24.0
23	19.31	19.3	19.3	8.0	24.92	24.8	25.0	23.0
24	19.25	19.2	19.3	8.0	24.34	24.2	24.4	22.0

#### 4.1.5 SUMMARY RESULTS OF PARAMETRIC STUDIES (TEST DESCRIPTION - ANNUAL USEFUL ENERGY - ENERGY COST)

**Table 4.1.1 SUMMARY RESULTS FOR RECTANGULAR SHAPE HOUSE-YEARLY ENERGY EQUIPMENT**

**Thermostat Setting: Winter-Summer 23 deg. C, Hours: 00.00 - 24.00**

**Infiltration Rate: Winter-Summer = 3 ac/h (or as in particular description)**

Code	Brief Description	UA	Heating		Cooling		Total	
No		w/m <sup>2</sup> k	(GJ)	CY£	(GJ)	CY£	(GJ)	CY£
RA	TYPICAL CYPRIOT HOUSE Existing case No optimization	1.88	62.99	252.00	49.94	405.00	112.93	657.00
RAa	Adding Insulation (25mm Polystyrene, R=0.61m <sup>2</sup> K/W) on RA (Externally On Roofs & Walls)	1.23	50.49	202.00	40.26	327.00	90.76	529.00
RAb	Adding Insulation of 50mm Polystyrene, R=1.22K/W	0.98	46.34	186.00	37.66	306.00	84.00	492.00
RAC	Re-Orientating windows (using "5000 Method") and adding overhangs and side-fins on RA	1.90	67.39	270.00	31.71	257.00	99.11	527.00
RB	Controlling Infiltration rate on RA i.e. winter=0.5 ac/h Summer = 0.5 ac/h (Day) 10 ac/h (Night)	1.88	26.90	108.00	42.36	344.00	69.27	452.00
RBa	Re-Orientating windows on RB using Microcomputer program "method 5000"	1.90	22.14	89.00	26.78	217.00	48.93	306.00
RBb	Changing Temperature Settings and hours on RB i.e. Winter T=19 deg. C hrs 6.00-9.00, 16.00-23.00, Summer T=26 deg. C hrs 12.00-19.00	1.88	7.43	30.00	10.46	85.00	17.89	115.00
RBC	Introduction of overhangs and side fins on wall surfaces of RB	1.90	30.17	121.00	24.78	200.00	54.96	321.00
RC	Adding Insulation 25mm Polystyrene R=0.61 (m <sup>2</sup> K/W) on RBC	1.25	18.07	73.00	15.65	127.00	33.73	200.00
RD	Altering thermostat settings of RBC i.e. Heating =21deg. C Cooling =24 deg. C	1.90	14.27	58.00	18.08	147.00	32.36	205.00
RE	Altering thermostat setting of RBb i.e. Heating = 19 deg. C Hrs = 06.00-24.00 Cooling=26 deg. C on RBC Hrs= 10.00 - 19.00	1.90	5.72	23.00	7.85	64.00	13.57	88.00
RF	Altering hours of equipment operation of RE i.e. Heating=6.00-9.00,16.00-23.00 Cooling -12.00 - 19.00 hrs	1.90	4.55	19.00	4.39	36.00	8.94	55.00

Note: For Further Information see 4.1 "THE OPTIMIZATION RESULTS" and Appendix 3.3.0



**Table 4.1.2 SUMMARY RESULTS FOR RECTANGULAR SHAPE HOUSE**

**Thermostat settings:**

**Summer - T = 26 deg. C, Hours: 12.00 - 19.00**

**Summer - T = 40 deg. C, Hours: 19.00 - 12.00**

**Winter - T = 19 deg. C, Hours : 06.00 - 09.00, 16.00 - 23.00**

**Winter - T = 10 deg. C, Hours : 09.00 - 16.00, 23.00 - 06.00**

**Infiltration Rate:**

**Winter** = 0.5 ac/h      **Hours:** 01.00 - 24.00

**Summer** = 0.5ac/h      **Hours:** 09.00 - 20.00

Summer = 10 ac/h Hours: 20.00 - 09.00 (otherwise as in particular Description)

Code	Brief Description	UA	Heating		Cooling		Total	
No		w/m <sup>2</sup> k	(GJ)	CY£	(GJ)	CY£	(GJ)	CY£
R1	Rectangular Shape - Base Uninsulated Partly optimized surface and window design	1.90	4.55	19.00	4.39	36.00	9.94	55.00
R1a	Changing Infiltration rate from 10 ac/h to 15 ac/h In Summer nights on R1	1.90	4.60	19.00	3.82	31.00	8.42	50.00
R2	Maximizing South Glazing (58.2m <sup>2</sup> ) Minimizing North glazing (0.50m <sup>2</sup> ) on R1	2.17	4.31	18.00	4.57	37.00	8.88	55.00
R3	Raising Overhang height above south glazing of R2, by 0.50m	2.17	3.48	14.00	4.59	38.00	8.08	52.00
R4	Introducing mass Internally on L2 by replacing 100mm BKW with 100mm Concrete wall	2.17	4.10	17.00	4.51	37.00	8.61	54.00
R5	Introducing mass externally on L4 by replacing 200mm BKW with 200mm Concrete wall	2.97	6.70	27.00	5.99	49.00	12.70	76.00
R6	Adding Insulation (50mm Polystyrene) R-1.22m <sup>2</sup> K/W externally on Roofs and walls of R4	1.36	1.33	6.00	1.39	12.00	2.72	18.00
R6a	Adding Insulation (50mm polystyrene) R-1.22m <sup>2</sup> K/W Internally on roofs and walls of R4	1.36	1.60	7.00	1.46	12.00	3.06	19.00
R6b	Adding Insulation (40mm Polystyrene R-1.00) Externally on walls and Roofs of R2	1.42	2.13	9.00	1.83	15.00	3.97	24.00
R7	Varying shape to the dimensions 11.67x7.5m on R6. (17.5 x 5.0m)	1.20	1.07	5.00	1.12	9.00	2.19	14.00
R12	Adding Insulation (50mm Polystyrene) externally on Roof ONLY, of R4 R-1.22 m <sup>2</sup> K/W	1.90	3.48	14.00	2.58	21.00	6.06	35.00

Note: For Further Information see 4.1 "THE RESULTS" and Appendix 3.3.0

**Table 4.1.3 SUMMARY RESULTS FOR L-SHAPE HOUSE**

**Thermostat settings:**

Summer- T = 26 deg. C, Hours: 12.00 - 19.00

Summer- T = 40 deg. C, Hours : 19.00 - 12.00

**Winter - T = 19 deg. C, Hours : 06.00 - 09.00, 16.00 - 23.00**

Winter - T = 10 deg. C, Hours : 09.00 - 16.00, 23.00 - 06.00

**Infiltration Rate:**

**Winter = 0.5 ac/h Hours : 01.00 - 24.00**

**Summer** = 0.5 ac/h      **Hours: 09.00 - 20.00**

**Summer = 10 ac/h Hours : 20.00 - 09.00 (otherwise as in particular Description)**

Code	Brief Description	UA	Heating		Cooling		Total	
No		W/m <sup>2</sup> K	(GJ)	CYE	(GJ)	CYE	(GJ)	CYE
L1	L-Shape-Base: Uninsulated, partly optimized surface and window design	1.88	4.73	19.00	5.16	42.00	9.89	61.00
L2	Maximizing South glazing (50.2m <sup>2</sup> ) Minimizing North glazing (1.75m <sup>2</sup> ) on L1	2.08	4.42	18.00	5.29	43.00	9.71	61.00
L3	Raising overhang height above south glazing of L2 by 0.50m	2.08	3.09	16.00	5.30	43.00	9.20	59.00
L4	Introducing mass Internally on L2 by replacing 100mm BKW with 100mm concrete wall	2.08	4.28	18.00	5.24	43.00	9.52	61.00
L5	Introducing mass externally on L4 by replacing 200mm BKW with 200mm concrete	2.92	7.22	29.00	7.49	61.00	14.71	90.00
L6	Adding Insulation (50mm Polystyrene Externally on Roofs and walls of P4	1.23	1.21	5.00	1.39	12.00	2.61	17.00

Note: For Further Information see 4.1 'THE RESULTS' and Appendix 3.3.0



Table 4.1.4 SUMMARY RESULTS FOR Π-SHAPE HOUSE

Thermostat settings:  
Summer - T = 26 deg. C, Hours : 12.00 - 19.00  
Summer - T = 40 deg. C, Hours : 19.00 - 12.00  
Winter - T = 19 deg. C, Hours : 06.00 - 09.00, 16.00 - 23.00  
Winter - T = 10 deg. C, Hours : 09.00 - 16.00, 23.00 - 06.00  
Infiltration Rate:  
Winter = 0.5 ac/h Hours : 01.00 - 24.00  
Summer = 0.5 ac/h Hours : 09.00 - 20.00  
Summer = 10 ac/h Hours : 20.00 - 09.00 (otherwise as in particular Description)

Code	Brief Description	UA	Heating		Cooling		Total	
No		W/m²K	(GJ)	CY£	(GJ)	CY£	(GJ)	CY£
Π1	Π-Shape-Base: UnInsulated, partly optimized surface and window (SG) design	1.89	4.24	17.00	5.20	43.00	9.45	60.00
Π2	Maxlmizing South glazing (49m²) Minimizing North glazing (2m²) on Π1	2.09	3.80	16.00	5.32	44.00	9.13	60.00
Π3	Raising overhang height above south glazing of Π2 by 0.50m	2.09	3.46	14.00	5.32	44.00	8.79	58.00
Π4	Introducing mass Internally on Π2 by replacing 100mm BKW with 100mm concrete	2.09	3.65	15.00	5.26	43.00	8.91	58.00
Π5	Introducing mass externally on Π4 by replacing 200mm BKW with 200mm concrete	2.91	6.34	26.00	7.60	62.00	13.94	88.00
Π6	Adding Insulation (50mm Polystyrene Externally on Roofs and walls of Π4	1.24	0.92	4.00	1.37	12.00	2.29	16.00

Note: For Further Information see 4.1 "THE RESULTS" and Appendix 3.3.0

Table 4.1.5 SUMMARY RESULTS FOR SQUARE SHAPE HOUSE

Thermostat settings:

Summer - T = 26 deg. C, Hours: 12.00 - 19.00  
Summer - T = 40 deg. C, Hours: 19.00 - 12.00  
Winter - T = 19 deg. C, Hours: 06.00 - 09.00 , 16.00 - 23.00  
Winter - T = 10 deg. C, Hours: 09.00 - 16.00, 23.00 - 06.00

Infiltration Rate:

Winter = 0.5 ac/h Hours: 01.00 - 24.00  
Summer = 0.5 ac/h Hours: 09.00 - 20.00  
Summer = 10 ac/h Hours: 20.00 - 09.00 (otherwise as in particular Description)

Code	Brief Description	UA	Heating		Cooling		Total	
No		w/m <sup>2</sup> k	(GJ)	CYE	(GJ)	CYE	(GJ)	CYE
S1	Square Shape Base: Uninsulated Partly optimized surface and window design	1.97	3.60	15.00	4.46	37.00	8.07	52.00
S2	Maximizing South Glazing (35.00 m <sup>2</sup> ) Minimizing North Glazing (4m <sup>2</sup> on S1)	2.03	3.56	15.00	4.50	37.00	8.06	52.00
S3	Raising overhang height above South glazing of S2 by 0.50m	2.03	3.04	13.00	4.51	37.00	7.56	50.00
S4	Introducing mass Internally on S2 by replacing 100mm BKW with 100mm Concrete	2.03	3.44	14.00	4.46	37.00	7.9	51.00
S5	Introducing mass externally on S4 by replacing 200mm BKW with 200mm Concrete wall	2.84	5.78	24.00	6.21	51.00	12.00	75.00
S6	Adding Insulation (50mm Polystyrene) externally on Roofs and walls of S4	1.16	0.97	4.00	1.17	10.00	2.15	14.00
S7	Varying Square shape half way to Rectangular. Dimension changes on S6	1.21	1.04	5.00	1.14	10.00	2.19	15.00
S8	Sandwiched Insulation in external cavity wall. Changes on S6.	1.16	1.01	4.00	1.14	10.00	2.15	14.00
S9	Replacing 100mm internal brick skin of external cavity wall in S8 with 100mm concrete	1.19	0.97	4.00	1.17	10.00	2.14	14.00
S10	Adding Insulation (50mm Polystyrene) on ground floor slab Variation on S6	1.16	0.84	4.00	1.53	13.00	2.37	17.00
S11	Replacing all Single-Glazing on S6 with all Double-Glazing	0.81	0.07	1.00	1.03	9.00	1.11	10.00



**Note: For further information see 4.1 "THE RESULTS" and Appendix 3.3.0**

## 4.2 THE ANALYSIS

### General

The analysis for the discussion of the results does not follow the order of comparative parametric studies as presented above (4.1 "The Results"). In the current chapter the results are discussed classified in four major variables:

1. **SHAPE**
2. **MASS**
3. **FENESTRATION**
4. **INSULATION**

The effect of the most important parameters of these variables, on the thermal response of the building is assessed during both heating and cooling modes. The performance of the parameters is analyzed, their efficiency is compared with each other and their effectiveness is expressed in the constructional aspects for a "Zero Energy House".

In order to avoid cluttering of the text, only the tables illustrating comparison of the reduction of energy consumption and cost to the reference design is presented in this section, as well as graphs and sample sensitivity plots illustrating the effect of main parameter variations on the thermal performance of the building. The data presented in the tables express quantitatively, in terms of percentages, the annual savings (in cost and useful energy for heating and cooling) the building design modification, its additional cost, and the pay back period. The calculations are made in comparison to the reference design.

The cost of the design modifications is calculated as the additional cost on the reference house design from prices obtained (May 1991) from the Cyprus government quantity surveyor of the Public Works department. It is expressed in Cyprus pounds (CP=0.80 Sterling Pounds). It can be observed that in most tests the percentage of savings in terms of money is not the same as the respective one in terms of useful energy savings in (GJ). This is because the savings are derived from the sum of heating and cooling and the cost of cooling is almost four times greater than that for heating as is mostly consumption of electricity whereas fuel for heating has lower cost as it is subsidised by the government.

In assessing the parameters, it was noted that their effect, or the full extend of their effect, it is not always expressed in the thermal response of the building to the stimuli parameters. This could be attributed either to limitations of the programme to encounter for them or lack of accuracy in modelling the simulations (3.2.2.4 "The Simulation Models"). The limitations and constraints of simulations will be discussed as the case might arise.

Finally from the analysis of the results conclusions are drawn for designing "Zero Energy Houses".



4.2.1 SHAPE

The shape is examined in four main variations an in combination with the other variables (3.2.2.2 "Variables, Varied Paraments, Using Data-Sets").

4.2.1.1 Basic Shape Variations

The comparison of the extend of the energy savings in the four shape variations is made having as reference their base-drawings (*R1, L1, Π1, S1, Appendix 3.3.0*). In the chart analysis of energy loading (*Graph 4.1*) The following are depicted:

- (i) The largest energy conservation for heating is achieved in the square shape, followed by the Π-shape, the L-shape and finally the rectangular.
- (ii) In terms of cooling energy savings the rectangular house is equally efficient as the square shape, followed by Π-shape along with the L-shape.
- (iii) Collectively the square shape achieves the largest amounts of energy savings. This is followed by the rectangular, the Π-shape and the L-shape.

Considering that all other design parameters are constant in all shape variations, there remains the extent, form and aspect of exposed surfaces as the only parameters in this test which determine the heating and cooling load. This indicates the higher potential inherent in the compactness of the form.

It was further observed that a small decrease of the roof area of the rectangular house, resulted to considerable cooling energy conservation and raised this shape from the last to the first position along with the square shape. This, further reinforces the issue that compact shapes are more economical than the more complex ones. The compactness of the square shape incurred lower heat loss than the three other shapes. The roof area decrease of the rectangular shape resulted to lower heat gains.

4.2.1.2 Shape and Fenestration - Maximizing South  
Minimizing North glazing surface area

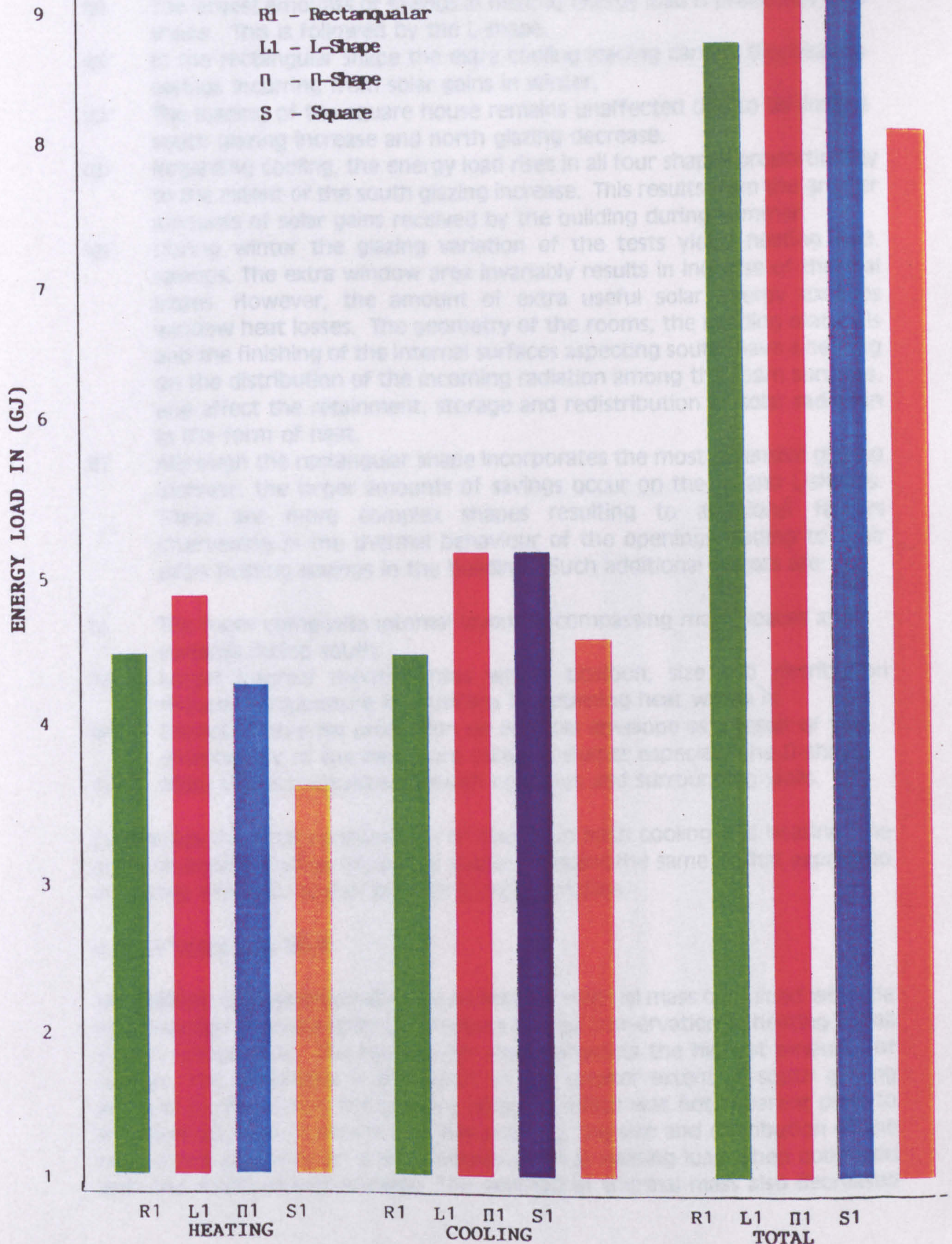
With this parameter variation, the glazing area (all in square meters) was altered as follows:

	North	South	
From	3.50	33.00	for all shapes
To	0.50	60.00	for R - shape
	1.75	50.00	for L - shape
	2.00	50.00	for Π - shape
	3.50	35.00	for S - shape



# SHAPE AND ANNUAL ENERGY LOAD

Graph 4.1: Energy consumption of the four basic shape - houses:





The effect of maximizing the south glazing area on the four shapes is expressed on the graphical illustration Graph 4.2 and is summarized as follows:

- (a) The largest amounts of savings in heating energy load is presented on  $\Pi$ -shape. This is followed by the L-shape.
- (b) In the rectangular shape the extra cooling loading cancels the heating savings incurring from solar gains in winter.
- (c) The loading of the square house remains unaffected due to its limited south glazing increase and north glazing decrease.
- (d) Regarding cooling, the energy load rises in all four shapes proportionally to the extent of the south glazing increase. This results from the greater amounts of solar gains received by the building during summer.
- (e) During winter the glazing variation of the tests yields heating fuel savings. The extra window area invariably results in increase of thermal losses. However, the amount of extra useful solar energy exceeds window heat losses. The geometry of the rooms, the building materials and the finishing of the internal surfaces aspecting south, have a bearing on the distribution of the incoming radiation among the room surfaces, and affect the retainment, storage and redistribution of solar radiation in the form of heat.
- (f) Although the rectangular shape incorporates the most extensive glazing increase, the larger amounts of savings occur on the  $\Pi$ - and L-shapes. These are more complex shapes resulting to additional factors intervening in the thermal behaviour of the openings leading to their extra heating savings in the building. Such additional factors are:
  - (i) The more composite internal layout encompassing more spaces and surfaces facing south.
  - (ii) Larger internal thermal mass whose position, size and distribution reduces temperature fluctuations by retaining heat within it.
  - (iii) Enhanced thermal protection on external envelope as a result of the morphology of the two more complex shapes especially the  $\Pi$ -shape.
  - (iv) More useful exchanges through openings and surrounding walls.

Comparing the total consumption of energy in both cooling and heating, the order of energy savings (in all four shapes) remains the same as that expressed in testing the basic shapes prior to glazing variation.

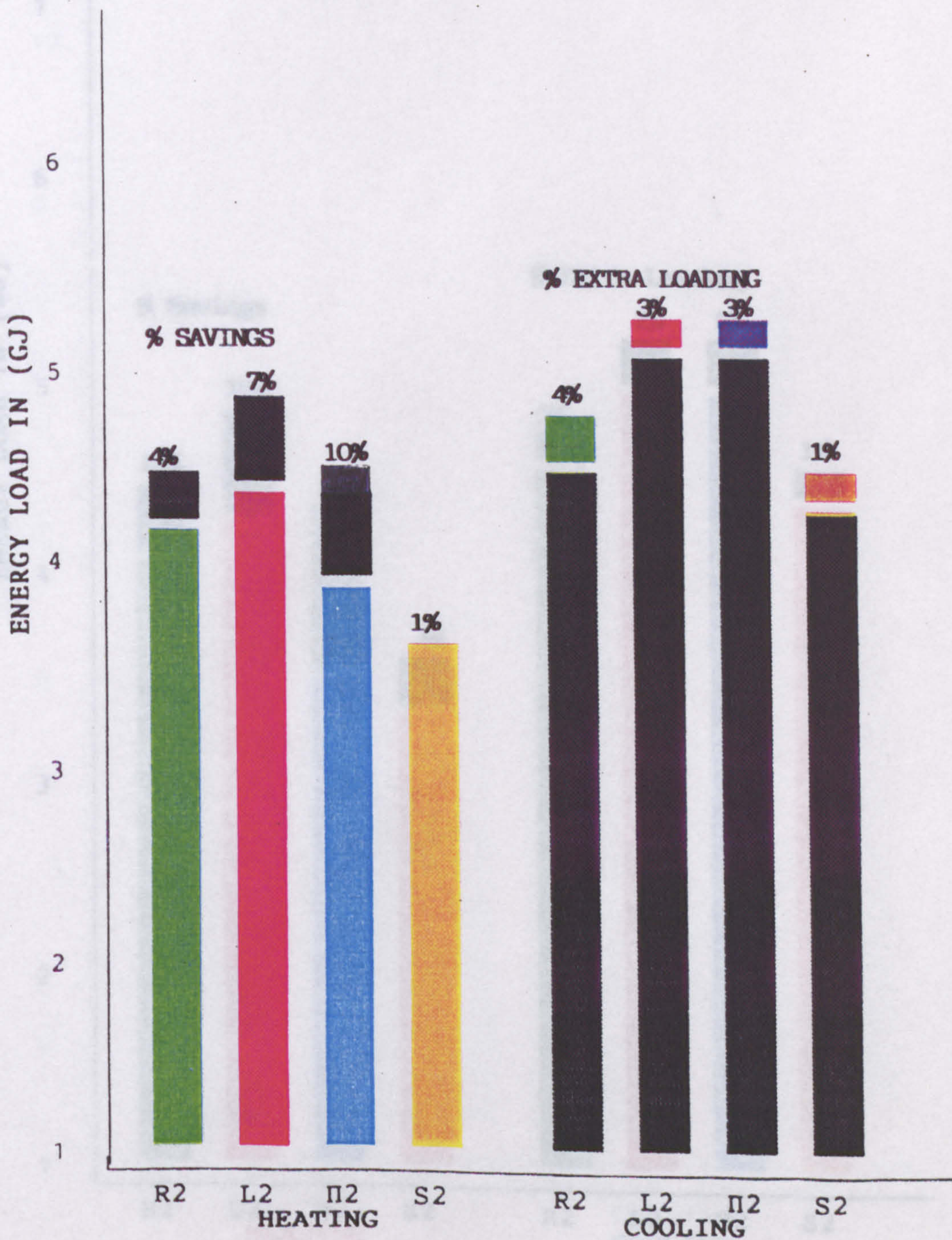
#### 4.2.1.3 Shape and Mass

**(a) Addition of Mass Internally:** The addition of internal mass combined with the maximization of south glazing, increases energy conservation in heating for all shapes (*Graph 4.3*). The rectangular shape presents the highest amounts of savings. This difference is attributed to the greater extent of south glazing increase on this shape, the positive effect of which was not apparent prior to the mass addition; it seems that the position, the size and distribution of the mass acted positively on energy conservation in heating load when combined with the south glazing increase. The addition of thermal mass also decreased



# SHAPE-SOUTH MAJOR GLAZING AND ENERGY LOAD

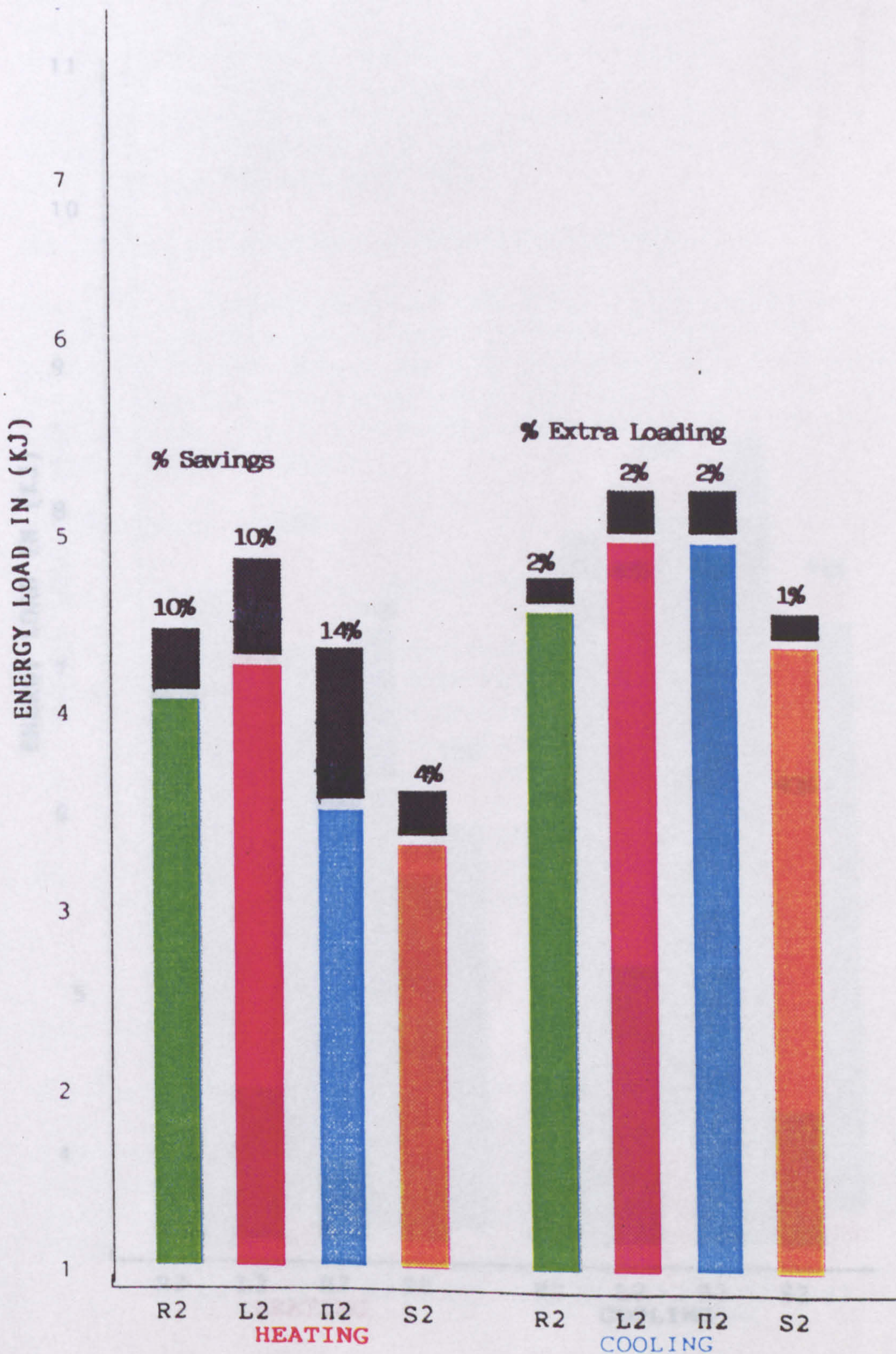
Graph 4.2: Energy consumption - % of saving and % of extra loading (top of column)  
(Reference Graph 4.1)





# SHAPE AND MASS INTERNALLY

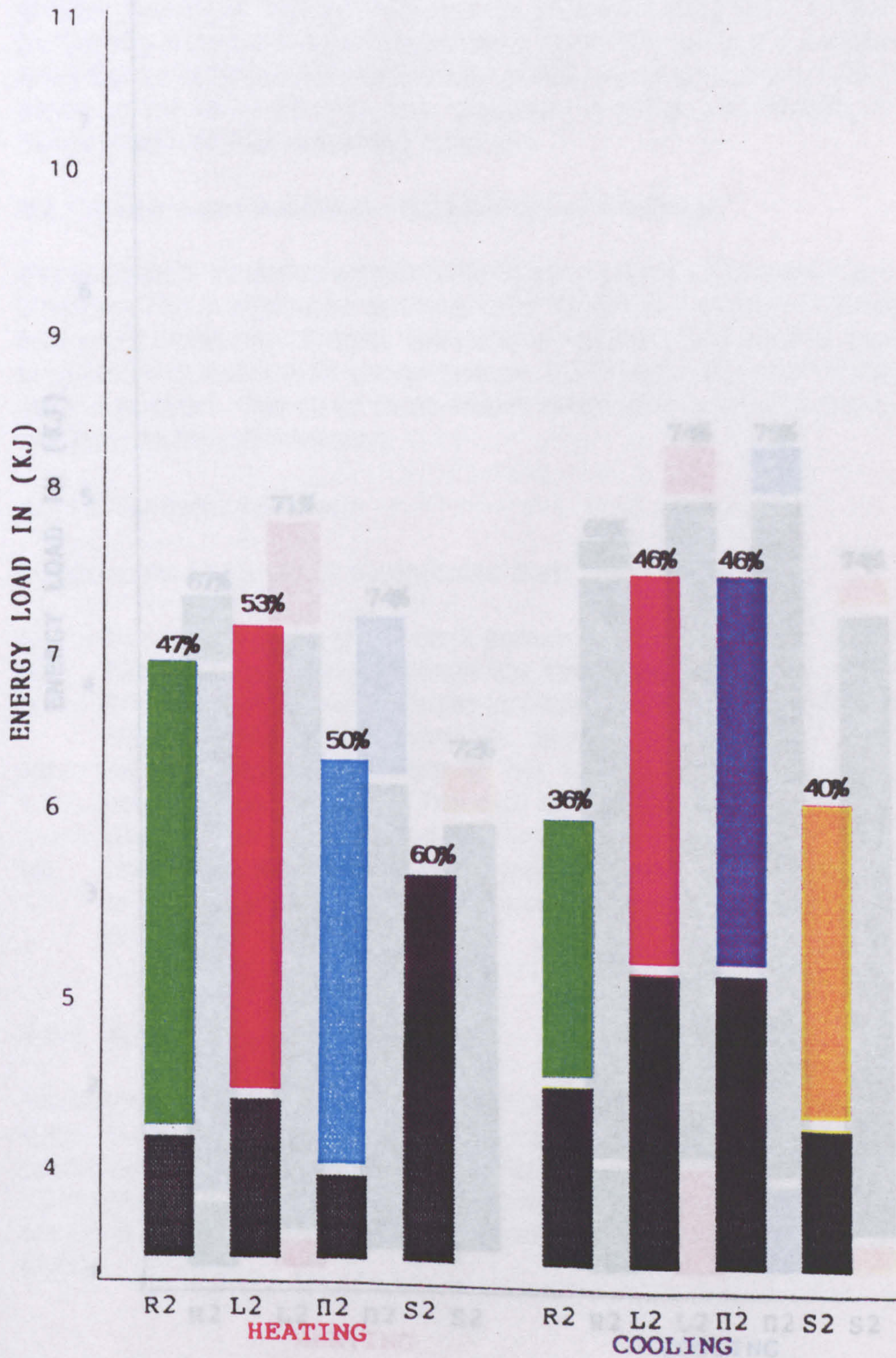
Graph 4.3: Energy consumption - % of additional savings due to mass introduction (Reference Graph 4.1)





# SHAPE-MASS EXTERNALLY AND ENERGY LOAD

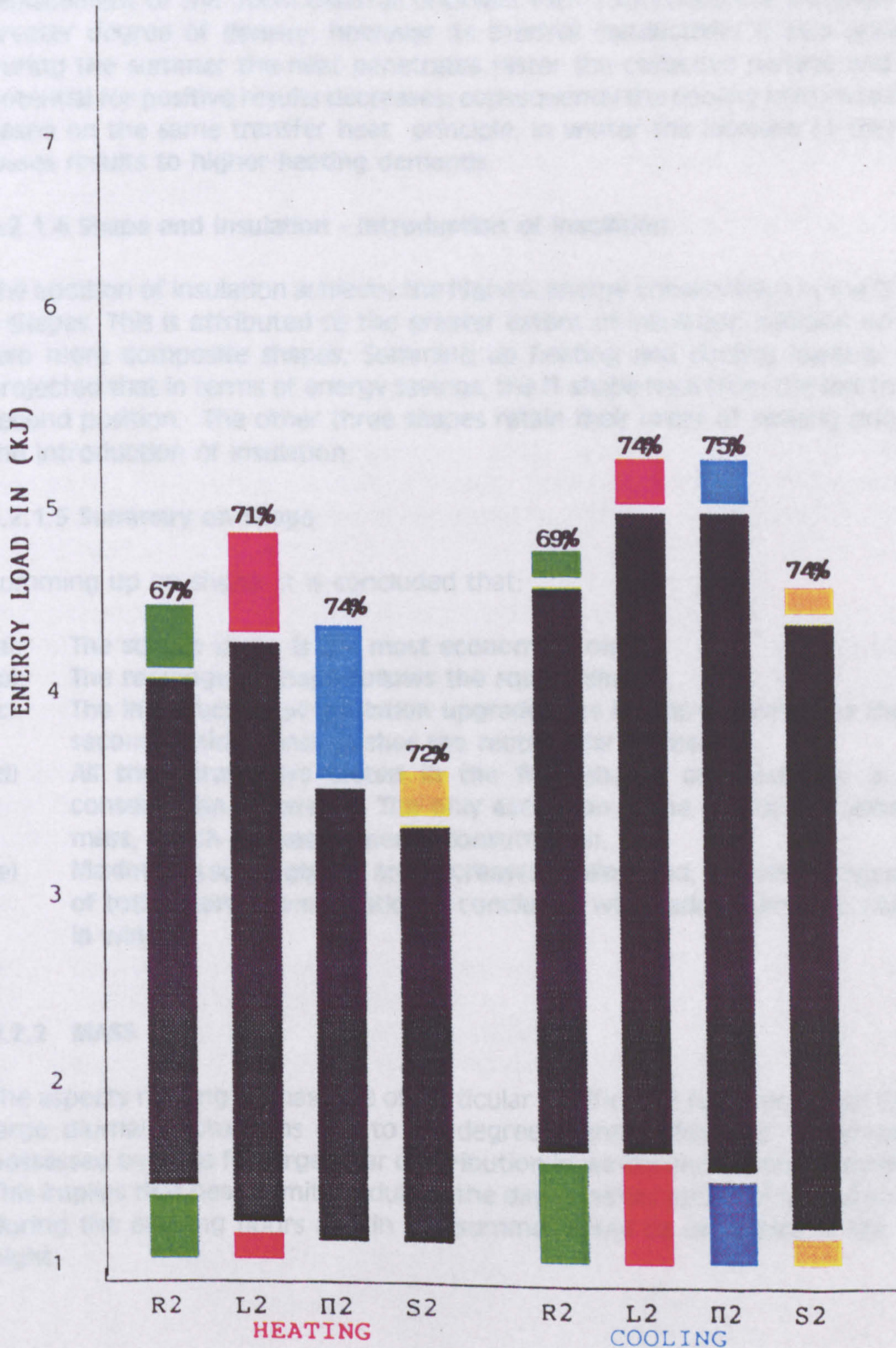
Graph 4.4: % of extra energy consumption  
(Reference Graph 4.1)





## SHAPE-INSULATION AND ENERGY LOAD

Graph 4.5: % of savings with introduction of insulation (Grey columns)  
(Reference Graph 4.3)





the cooling load in all shapes. The energy reduction is due to the potential of the mass to retain the coolness of the night. When summing up energy consumption in both heating and cooling, it is observed that the square shape retains its lead in being the most economical house. The compactness of the shape seems to overshadow the other test variables.

**(b) Shape and Addition of Mass Externally:** The addition of external mass affects adversely the conservation of energy in all four shapes (*Graph 4.4*). The replacement of the 20cm external brickwall with 20cm concrete although has greater degree of density, however its thermal conductivity is also greater. During the summer the heat penetrates faster the collective surface and the potential for positive results decreases; consequently the cooling load increases. Based on the same transfer heat principle, in winter the increase of thermal losses results to higher heating demands.

#### **4.2.1.4 Shape and Insulation - Introduction of Insulation**

The addition of insulation achieves the highest energy conservation in the  $\Pi$  and L shapes. This is attributed to the greater extent of insulation addition on the two more composite shapes. Summing up heating and cooling loading, it is projected that in terms of energy savings, the  $\Pi$ -shape rises from the last to the second position. The other three shapes retain their order of ranking prior to the introduction of insulation.

#### **4.2.1.5 Summary on Shape**

Summing up on shape it is concluded that:

- (a) The square shape is the most economical one.**
- (b) The rectangular shape follows the square shape.**
- (c) The introduction of insulation upgrades the  $\Pi$ -shape, raises it to the second position and pushes the rectangular to the last.**
- (d) All the parameters tested in the four shapes act positively in the conservation of energy. The only exception is the addition of external mass, which increases energy consumption.**
- (e) Maximizing south glazing area increases cooling load. However, reduction of total energy consumption is concluded when adding heating savings in winter.**

### **4.2.2 MASS**

The aspects relating to mass are of particular significance for Cyprus due to the large diurnal fluctuations (15 to 25 degrees centigrade), and the potential possessed by mass for large solar contribution in winter and cooling in summer. This implies that heat admitted during the day in winter could be stored for use during the evening hours and in the summer could be dissipated in the cool night.



The addition of mass has already been examined in relation to the house shape. The study has shown that addition of internal mass incurs energy conservation of varied extent according to the thermal behaviour of each shape. On the contrary addition of external mass leads to higher energy consumption in all shapes (*Graphs 4.3, 4.4*). Whereas masonry provides good heat storage medium within a space, it readily passes this heat to the outside when added on exterior walls.

The concept of addition of mass is presented as an acceptable modification of the walls construction in the Cyprus marketplace (3.2.2.2. "Variables, Varied Parameters - Using Data-Sets"). The studies of addition of mass, result at the following percentages regarding energy consumption:

- (i) The addition of internal mass yields to 5% reduction of cooling as well as heating load.
- (ii) The addition of external mass increases energy consumption by 40%.

A further 30% of internal mass, expressed in the design as additional internal wall, leaves the energy consumption of the house unaffected. This could be attributed to the orientation of the additional mass. A south orientation allows greater insolation in winter and the mass absorbs, stores and dissipates more heat. Another possible reason could be the quantity of the mass. From the studies it appears that the extent of mass increase seems to be critical concerning its effect on the energy loading. Extensive increase of internal mass could act adversely in as far as time needed to cool it in the summer nights or indeed heat it in the winter.

The mass variable was also examined on a thermally improved building and the energy savings compared with those incurring from an unimproved structure. The figures of decrease and increase of energy consumption shrunk correspondingly for both the addition of internal and external mass.

In order to determine the full extent of the effect of mass on the thermal behaviour of the building further analysis is necessary concerning parameters such as:

- (a) Collective and storage characteristics of the materials of the surface finishing.
- (b) Location, quantity, distribution and surface colour of mass.
- (c) Orientation of internal surfaces.
- (d) Diurnal and spatial temperature swings.
- (e) Combination of window sizing and extent of thermal mass.

However the mass parameters tested on the current studies were sufficiently indicative as to determine their effect. The addition of internal mass was positive and thus employed as energy conservation measure to reach the zero energy house.



### 4.2.3 FENESTRATION

The thermal response of the building within the range of tests regarding fenestration design (3.2.2.2 "Variables, Varied Parameters - Using Data-Sets") is examined in the following pages.

#### 4.2.3.1 Orientation and glazing area

Although a series of simulations on micro-computer programme "5000 Method" indicates that a major glazing area with southerly aspect gives favourable energy load balance, it is considered important to assess the energy savings and the effect of glazing in respect to orientation, in relative terms with the other parameters which bear the same design consistency within this range of tests. The total glazing area is kept constant ( $32.00\text{m}^2$ ) for all the tests. The two orientations studied in the tests are the following:

- (a) Uniform distribution of the glazing area ( $8.00\text{m}^2$  on each side) on the four sides (North, East, South West) of the reference house (RA).
- (b) Re-orientation of the glazing on the reference house, concentrating the 70% of the total glazing to the south ( $28.50\text{m}^2$ ), restricting North glazing to  $3.50\text{m}^2$ , (15%) and eliminating it on the east and west sides (test no. RAf).

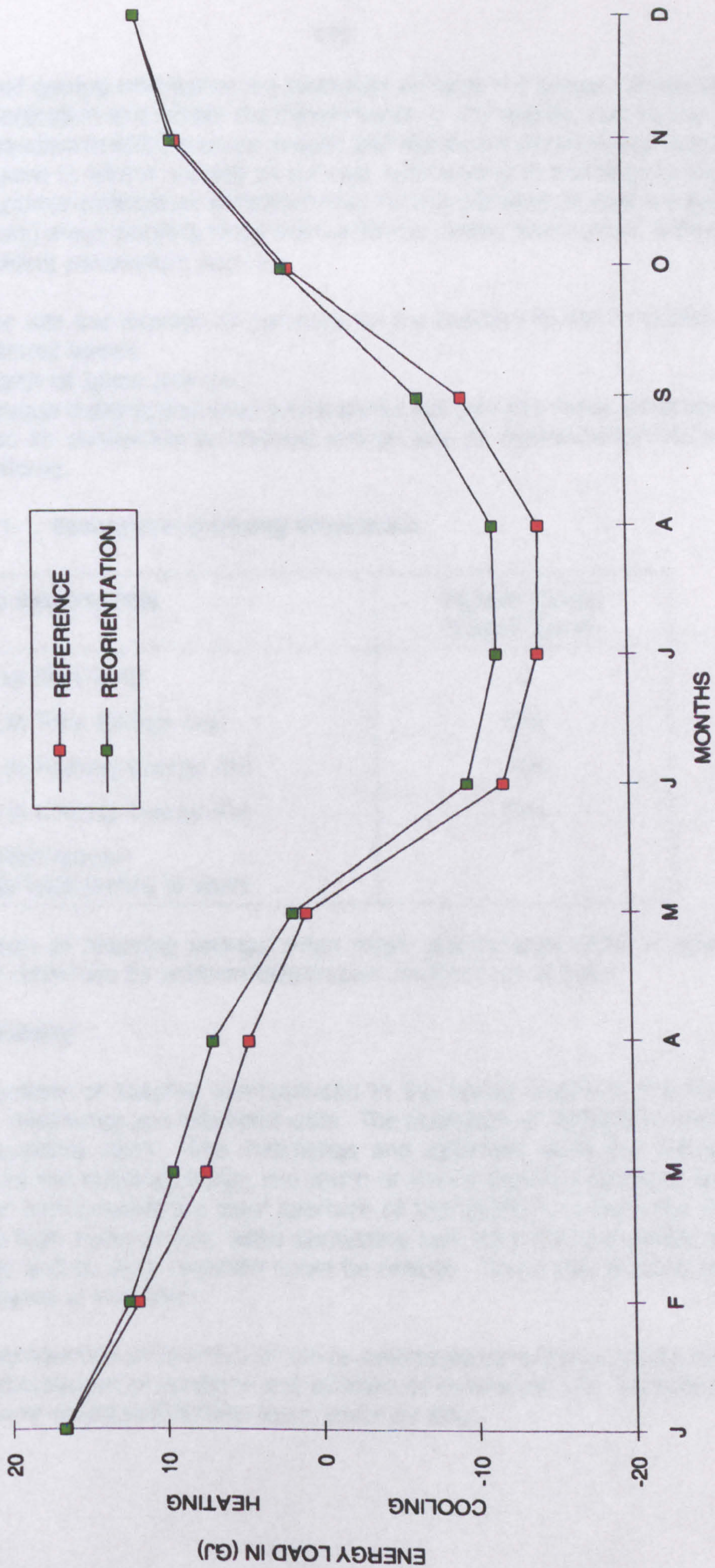
The re-orientation of glazing was further studied in conjunction with shading and infiltration rate (see (b) Shading and (c) Infiltration rate below). The graph 4.8 indicates the effect on energy load by concentrating fenestration on the south side with reference to its uniform distribution on all four sides. From the graph the following are observed regarding maximization of the south glazing area:

- (i) This approach does not involve any extra cost and results to 11% savings in money when compared with reference design. This amounts to 70.00CYP/year.
- (ii) The cooling energy load is significantly decreased during the hot summer months. This incurs 22% cooling savings (*Table 4.1*). This results mainly from the removal of all openings on East and West sides thus avoiding overheating in the mornings and the afternoons from these two sides (*Graph 4.8*).
- (iii) During winter especially in February, March, October and November energy heating load increases. This results to a reduction of heat savings by 10%. The reduction of heating savings is due to the avoidance of glazing on east and west side of the building and therefore the elimination of solar gains during spring and autumn seasons.

From a results analysis, concerning heat gains, it is gathered that by removing fenestration from East and West sides, Winter solar gains are reduced affecting the thermal window balance (i.e thermal gains minus losses) and yields negatively for the heating load. In addition to the above, results regarding



GRAPH 4.8: SOUTH GLAZING AND ENERGY LOAD





savings and glazing orientation are tabulated on table 4.1 below. These results are only indicative and reflect the performance of the specific test house-case. The fenestration orientation is a complex, and significant determining factor, for thermal gains in winter, as well as summer overheating in buildings in Cyprus. For the optimal orientation of fenestration further detailed studies are needed for each and every building since this variable is closely interrelated with many other building parameters such as:

- (i) The size and location of openings on the building facade in relation to:
- (ii) Internal layout
- (iii) Depth of space and the
- (iv) Opaque building elements which affect not only the direct insolation but also its conversion to thermal energy and its redistribution inside the building.

Table 4.1: Economics of Glazing Orientation.

GLAZING ORIENTATION	28.50m <sup>2</sup> -South 3.50m <sup>2</sup> -North
Additional Cost in CY	0
Savings in Total Energy cost	11%
Savings in Heating Energy (GJ)	-10%
Savings in Cooling Energy (GJ)	22%
Cost Effectiveness/ Pay-back period in years	0

*Comparison of resulting savings when major glazing area (70%) is aspecting South to reference its uniform distribution (8.00m<sup>2</sup>) on all sides.*

4.2.3.2 Shading

The parameter of shading is introduced in the house design in the form of shutters, overhangs and extended walls. The operation of shutters is controlled by the building users. The overhangs and extended walls are permanent features of the building design; the width of their projection has been defined so that in the summer the solar aperture of the glazing is completely shaded from the high summer sun, while permitting rays from the low winter sun to penetrate and so solar radiation could be utilized. These two shading devices are examined in two tests:

- (a) Introduction of shutters on the re-orientated fenestration (*tests no:RAe*).
- (b) Introduction of shutters and addition of overhangs and extended walls on re-orientated fenestration (*tests on RAc*).

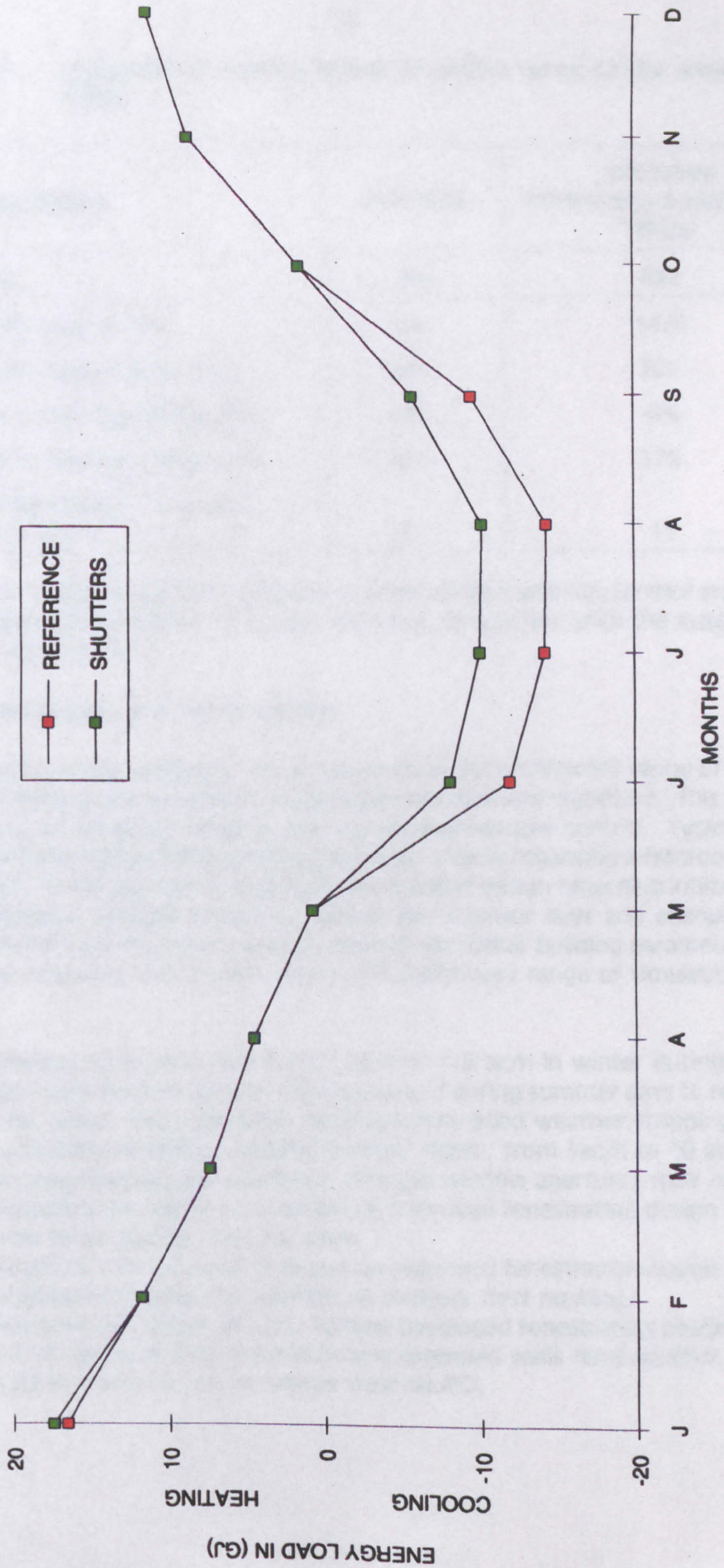


- (a) **Introduction of shutters** As shown on the graph 4.9 the introduction of controllable shading devices (shutters) to intercept the summer sun, incurs considerable reduction of cooling;
  - (i) The total savings in terms of money are increased *by 30% (test no:RAe)*. The cooling savings alone are 42% while the heating load is increased by 10%.
  - (ii) The design assumes an outlay of 500 CYP, requiring three years payback period.
  - (iii) The introduction of shutters as solar protection method achieves higher energy conservation than re-orientating fenestration; The unwanted summer solar radiation is intercepted, whilst the desired winter solar gains are almost unaffected, thus reducing considerably the cooling load.
- (b) **Introduction of shutters and addition of overhangs and extended walls.** Incorporating further in the design fixed shading devices of overhangs and extended walls also concludes to energy savings (*Graph 4.10*):
  - (i) The total savings are 20% for both heating and cooling.
  - (ii) This is by 10% less savings than those achieved by the introduction of shutters only.
  - (iii) There is 5% reduction of the heating savings which is attributed to the loss of useful solar gains intercepted by permanent overhangs and extended walls.
  - (iv) There is also 5% loss of cooling savings which is attributed to the retention of heat by the additional external mass of overhangs and extended walls.
  - (v) The combined shading measure of shutters, overhangs and extended walls saves 130 CYP/year. Considering the savings reduction and the additional construction cost of the fixed shading devices, a pay-back period of 11 years is estimated.

It is noted that the full extend to which shutters, overhangs, and extended walls affect the thermal response of the building is not fully expressed in the tests under study. The additional mass, the insulative, reflective and other properties of these components, associated with heat transfer carry the prospect of positively affecting the energy savings of the building. Such indications were not conveyed by the concerned tests. The introduction of shading devices in the building configuration is translated in the simulations only as interception of the sun. This is attributed to the programme's inadequacy to register the affecting characteristics and aspects of these components. In table no:4.2 below comparison of the two shading measures above can be made in relative terms with each other and to the reference design.



GRAPH 4.9: SHUTTERS AND MONTHLY ENERGY LOAD





**Table 4.2: Economics of shading devices in relative terms to the reference design.**

SHADING DESIGN	SHUTTERS	SHUTTERS OVERHANGS & EXTENDED WALLS
TEST NO	RAe	RAc
Additional cost in CYP	: 500	1425
Savings in Total Energy Cost	: 30%	20%
Savings in Heating Energy (GJ)	: -12%	-8%
Savings in Cooling Energy (GJ)	: 42%	37%
Cost Effectiveness/ Pay-back Period in Years	: 3	11

Shading is combined with the infiltration rates variable and was further studied in Infiltration Rates below. It is also studied in conjunction with the insulation variable (*test no:Rc*).

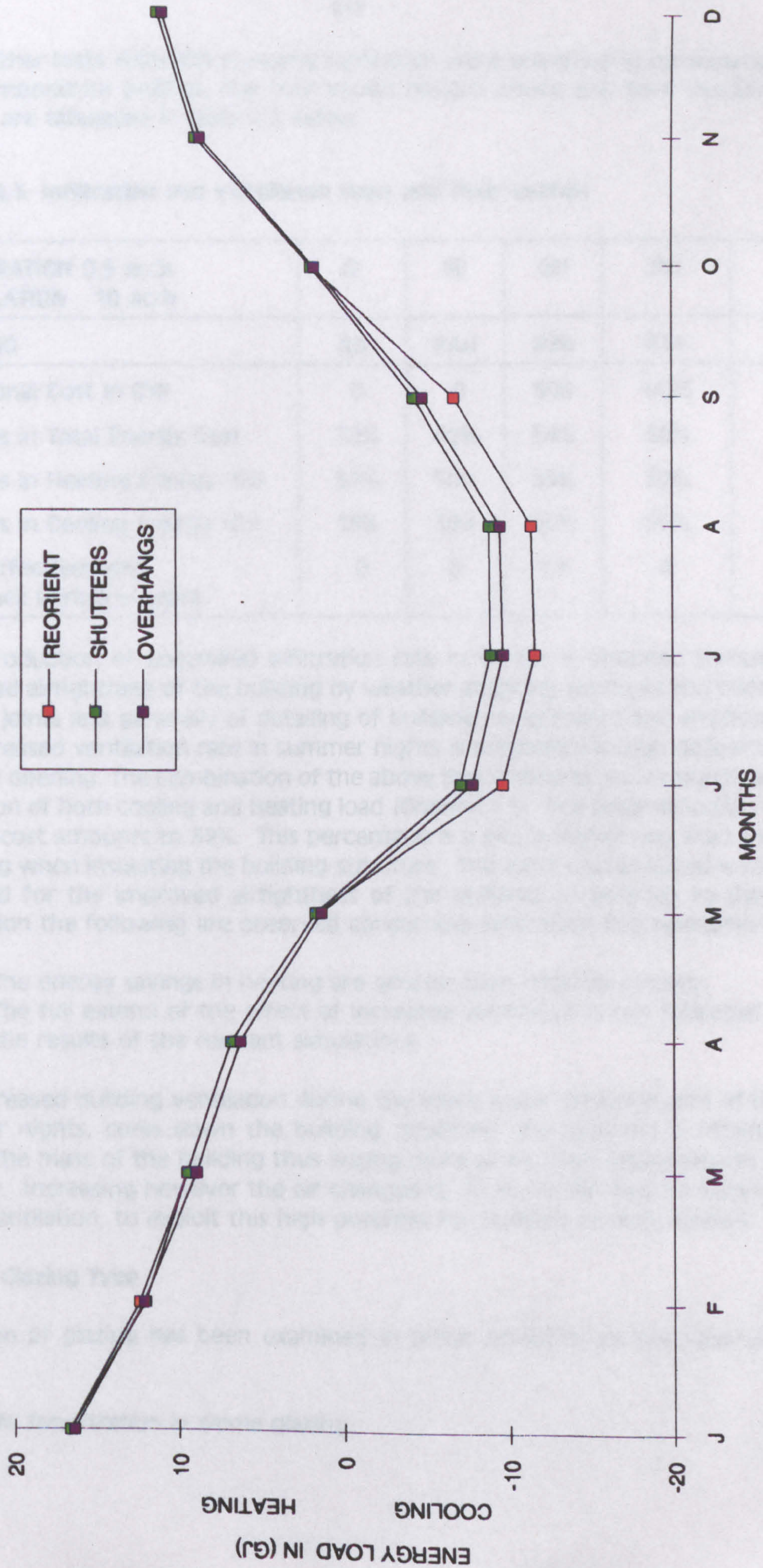
#### 4.2.3.3 Infiltration rate and Ventilation

The infiltration and ventilation value employed in the preliminary range of tests is 3 ac/h throughout all seasons during both, daytime and nighttime. This value assumes poor weathers tripping and unattended window control. Typically it represents the conventional building practice in Cyprus regarding infiltration and ventilation. In the process of improving the building design regarding infiltration and ventilation, airtight design for winter and summer days and encouraged ventilation in summer nights, were combined with other building parameters to form the following test profiles within the preliminary range of simulations:

- (i) Altering infiltration rate from 3 ac/h to 0.5 ac/h in winter during both days and nights to restrict heat losses and during summer days to reduce heat gains. This infiltration value assumes good weather stripping. Increasing ventilation, during summer nights, from 3ac/h to 10 ac/h by encouraging natural ventilation through window apertures (*test no:RB*).
- (ii) Adopting the values of (i) above on improved fenestration design of re-orientated glazing (*test no: RAd*).
- (iii) Adopting the values of (i) above on improved fenestration design of re-orientated glazing and addition of shutters (*test no:RBa*).
- (iv) Adopting the values of (i) on further developed fenestration design than (iii) above by adding overhangs and extended walls (*test no:RBc*).
- (v) Adding insulation on (iv) above (*test no:RC*).



GRAPH 4.10: OVERHANGS - SIDEFINS AND MONTHLY ENERGY LOAD





Two further tests (*RBb*, *RD*) involving infiltration were examined in combination with temperature profiles. The four varied designs above and their resulting savings are tabulated in table 4.3 below.

**Table 4.3: Infiltration and Ventilation tests and their savings**

INFILTRATION 0.5 ac/h VENTILATION 10 ac/h	(i)	(ii)	(iii)	(iv)	(v)
TEST NO	RB	RAd	RBa	RBc	RC
Additional Cost in CYP	0	0	500	1425	2785
Savings in Total Energy Cost	32%	42%	54%	50%	70%
Savings in Heating Energy (GJ)	57%	50%	65%	52%	71%
Savings in Cooling Energy (GJ)	15%	35%	46%	50%	69%
Cost Effectiveness/ Pay-back Period in years	0	0	1.5	4	5.5

The introduction of controlled infiltration rate in winter is obtained through improved airtightness of the building by weather stripping windows and taking care to joints and generally of detailing of building components and envelope. The increased ventilation rate in summer nights is achieved through deliberate window opening. The combination of the above two measures incurs significant reduction of both cooling and heating load (*Graph 4.11*). The total reduction of energy cost amounts to 32%. This percentage is a much higher one than that resulting when insulating the building structure. The extra cost involved is that assumed for the improved airtightness of the building. In addition to these conclusion the following are observed concerning infiltration and ventilation:

- (i) The energy savings in heating are greater than those in cooling.
- (ii) The full extend of the effect of increased ventilation is not reflected in the results of the relevant simulations.

The increased building ventilation during the much lower temperatures of the summer nights, cools down the building structure; The coolness is retained within the mass of the building thus lasting more at the high temperatures of the day. Increasing however the air changes to 10 or 15 per hour as summer night ventilation, to exploit this high potential for building cooling, limited.

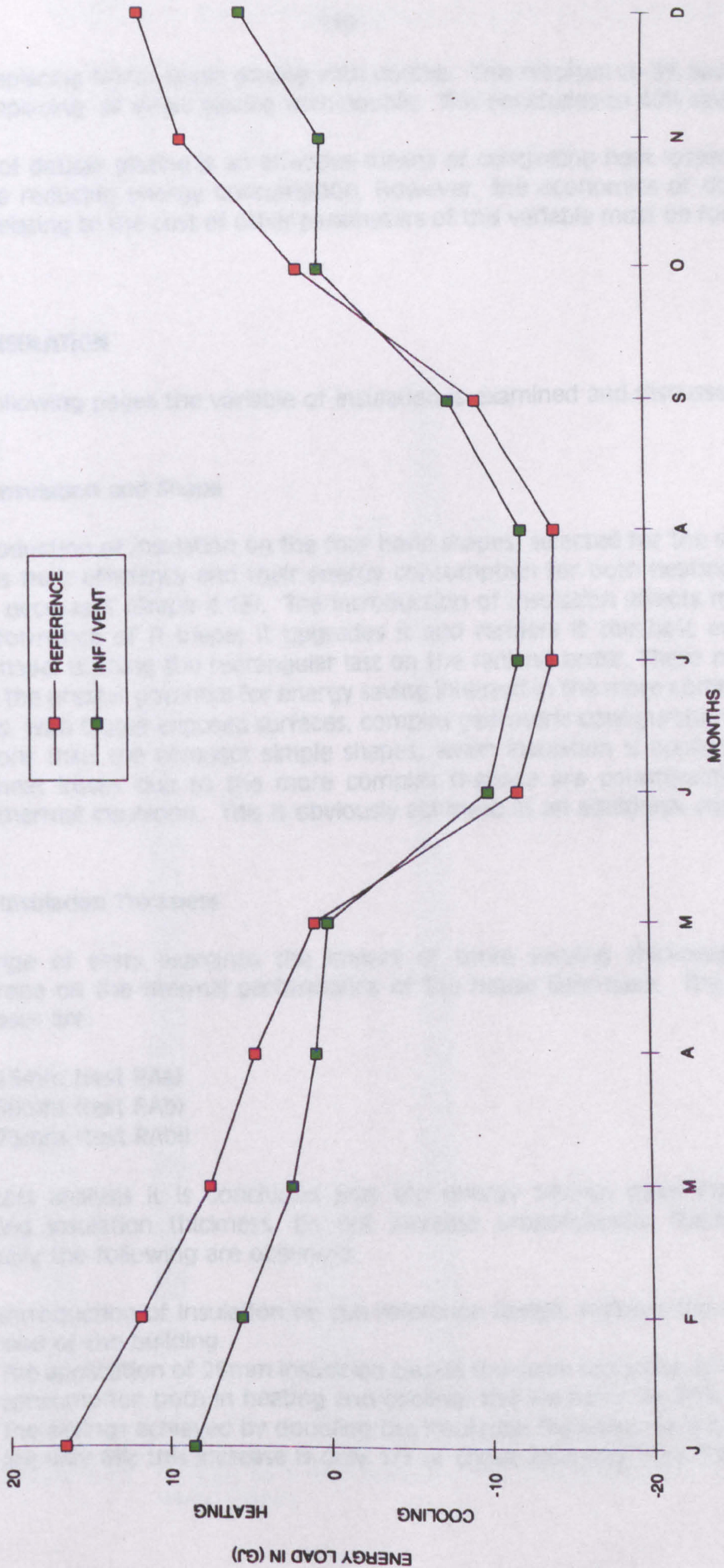
#### 4.2.3.4 Glazing Type

The type of glazing has been examined in three variations on the base-case house:

- (a) All fenestration in single glazing



GRAPH 4.11: INFILTRATION RATE AND MONTHLY ENERGY LOAD





- (b) Replacing North single glazing with double. This resulted to 6% savings.
- (c) Replacing all single glazing with double. This concludes to 48% savings.

The use of double glazing is an effective means of controlling heat losses and therefore reducing energy consumption. However, the economics of double glazing relating to the cost of other parameters of this variable must be further studied.

#### 4.2.4 INSULATION

In the following pages the variable of insulation is examined and discussed.

##### 4.2.4.1 Insulation and Shape

The introduction of insulation on the four basic shapes, selected for the study, improves their efficiency and their energy consumption for both heating and cooling, decreases (*Graph 4.13*). The introduction of Insulation affects mostly the performance of  $\Pi$ -shape; it upgrades it and renders it the best energy saving shape, pushing the rectangular last on the ranking order. These results indicate the greater potential for energy saving inherent in the more composite buildings, with bigger exposed surfaces, complex geometric configurations and projections than the compact simple shapes, when insulation is applied. The higher heat losses due to the more complex  $\Pi$ -shape are counteracted by adding thermal insulation. This is obviously achieved at an additional cost.

##### 4.2.4.2 Insulation Thickness

This range of tests examines the impact of three varying thicknesses of polystyrene on the thermal performance of the house Base-case. The three thicknesses are:

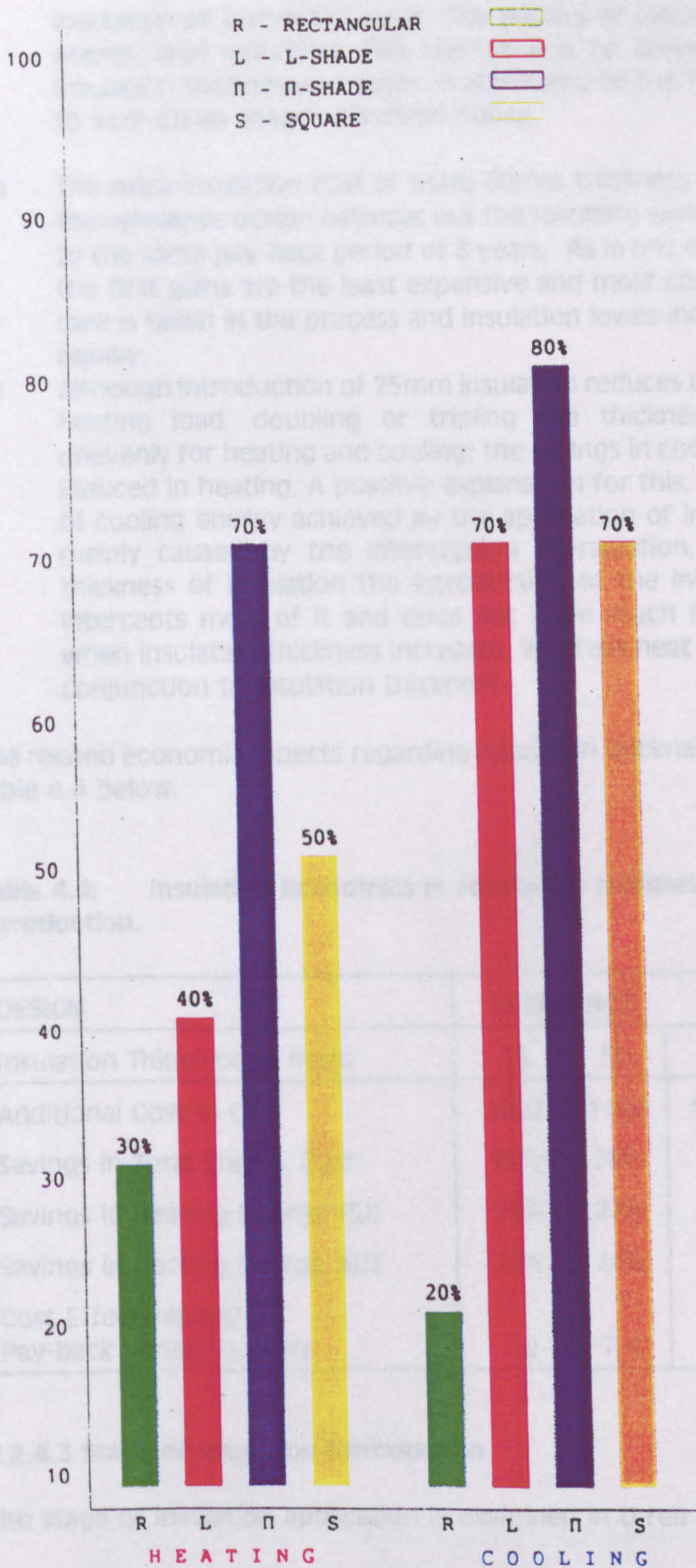
- (a) 25mm (test RAa)
- (b) 50mm (test RAb)
- (c) 75mm (test RAbi)

From test analysis it is concluded that the energy savings incurring from increasing insulation thickness, do not increase proportionally (*Table 4.4*). Specifically the following are observed:

- (i) Introduction of insulation on the reference design, reduces the energy load of the building.
- (ii) The application of 25mm insulation causes the same reduction of energy consumption both in heating and cooling; this amounts to 20%.
- (iii) The savings achieved by doubling the insulation thickness on the design are only 6%; this increase is only 1/3 of those incurring from the initial



# ENERGY SAVINGS INSULATION AND SHAPE



Graph 4.13: Savings in % when insulation is introduced on the four basic shapes.



insulation of 25mm thickness. The tripling of insulation causes only 3% energy load reduction. This low amount of savings difference, when insulation thickness increases, is attributed to the fact that there is less to save on an already insulated house.

- (iv) The extra insulation cost of using 50mm thickness instead of 25mm on the reference design balances out the resulting savings and so concludes to the same pay-back period of 8 years. As in any conservation strategy the first gains are the least expensive and most cost effective. As more care is taken in the process and insulation levels increase, costs escalate rapidly.
- (v) Although introduction of 25mm insulation reduces uniformly cooling and heating load, doubling or tripling the thickness increases savings unevenly for heating and cooling; the savings in cooling are half of those induced in heating. A possible explanation for this, is that the reduction of cooling energy achieved by the application of insulation externally is mainly caused by the interception of radiation, irrespective of the thickness of insulation the introduction of the initial 25mm insulation intercepts most of it and does not leave much for further reduction when insulation thickness increases. Whereas heat transfer is resisted in conjunction to insulation thickness.

The related economic aspects regarding insulation thickness are summarized on table 4.4 below.

**Table 4.4:     Insulation Economics in relation to thickness and stage of its introduction.**

DESIGN	REFERENCE			IMPROVED	
Insulation Thickness in (mm)	25	50	75	25	50
Additional Cost in CYP	1023	1160	1300	1023	1160
Savings in Total Energy Cost	20%	26%	29%	41%	52%
Savings in Heating Energy (GJ)	20%	27%	30%	40%	59%
Savings in Cooling Energy (GJ)	20%	24%	28%	37%	47%
Cost Effectiveness/ Pay-back period in years	7.9	7.0	6.5	7.7	6.9

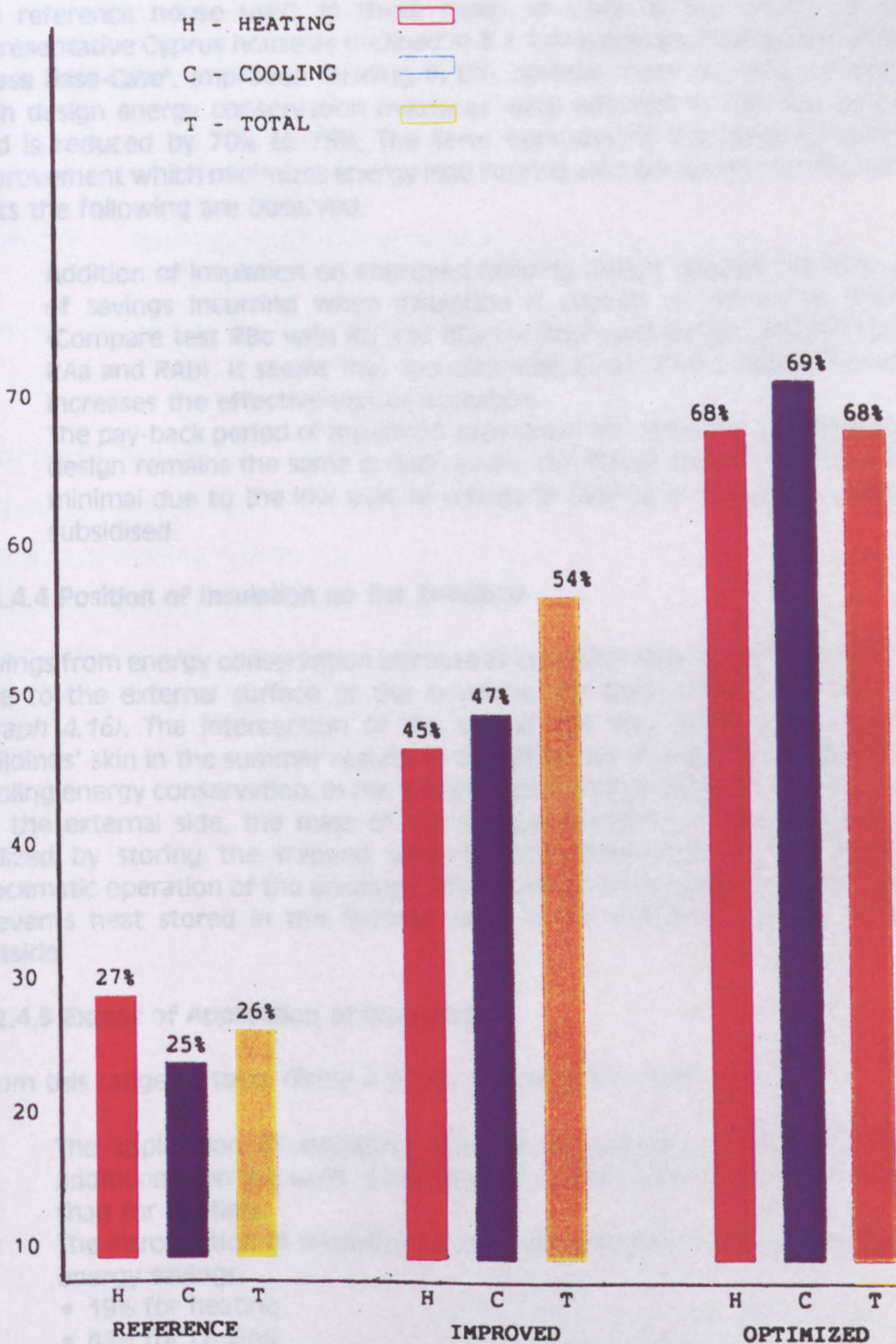
**4.2.4.3 Stage of Insulation Introduction**

The stage of insulation application is examined in three phases (*Graph 4.15*):

- (i)     On the reference house "Base-case"



# ANNUAL ENERGY SAVINGS (GJ) ON VARIED HOUSE DESIGN



Graph 4.15: Design stage of insulation introduction and savings %.



- (ii) On an improved house
- (iii) On optimized house

The reference house used, in these series of tests, is the profile of the representative Cyprus house as outlined in 3.2.1.4 "Summary Description of the House Base-Case". Improved building in this context is the building on which such design energy conservation measures were adopted so that the energy load is reduced by 70% to 75%. The term optimized is the stage of design improvement which minimizes energy load nearing zero consumption. From the tests the following are observed:

- (i) Addition of insulation on improved building design doubles the amount of savings incurring when insulation is applied on reference design (Compare test RBc with RC and RCa for improved design, and RA with RAa and RAb). It seems that the combination of other design measures increases the effectiveness of insulation.
- (ii) The pay-back period of insulation application on reference and improved design remains the same in both cases; the actual savings in money are minimal due to the low cost of energy in Cyprus, as fuel for heating is subsidised.

#### 4.2.4.4 Position of Insulation on the Envelope

Savings from energy conservation increase as insulation moves from the internal side to the external surface of the envelope, for both cooling and heating (*Graph 4.16*). The interception of the sun at the very external side of the buildings' skin in the summer results to the efficiency of external insulation for cooling energy conservation. In the winter with the positioning of the insulation on the external side, the mass of the opaque elements of the structure, is utilized by storing the trapped solar energy contributing to the efficient bioclimatic operation of the building. The insulation on the exterior of envelope prevents heat stored in the thermal mass to be conducted rapidly to the outside.

#### 4.2.4.5 Extent of Application of Insulation

From this range of tests (*Table 4.5*) the following are concluded:

- (i) The application of insulation whether exclusively on the roof or/and additionally on the walls, incurs greater energy conservation for cooling than for heating.
- (ii) The introduction of insulation on the roof presents a high percentage of energy savings:
  - 19% for heating
  - 45% for cooling
- (iii) Extending insulation on the walls increases savings only by 5% for heating and 5% for cooling.
- (iv) The additional cost for extending insulation on walls rises the pay-back



- period needed for roof insulation only, from 7.5 years to 45 years.
- (v) The application of insulation on the floor has adverse effects on the efficiency of the house thermal performance; from simulation analysis is indicated that floor insulation prevents the natural thermal processes, for the climatic conditions of Cyprus, which inherently are more effective without insulation.

The related economic aspects regarding the extent of insulation application are summarized in table 4.5 below.

**Table 4.5: Insulation economics in relation to extent of its application on the building envelope.**

EXTENT OF INSULATION			
	ROOF	R+ WALLS	R+ W+ FLOOR
Additional Cost in CYP	150	900	1050
Savings in Total Energy Cost	37%	56%	-18%
Savings in Heating Energy (GJ)	19%	72%	0
Savings in Cooling Energy (GJ)	46%	60%	-23%
Cost Effectiveness/ Pay-back period in years	7.5	45	--



# POSITION OF INSULATION AND % OF ENERGY SAVINGS



Graph 4.16: Position of insulation on the house Envelope and energy savings in %.



### 4.3 SUMMARY AND CONCLUSIONS

From the above test analysis the most effective parameters of the four main variables are summarized below.

#### 4.3.1 Shape

**Basic Shapes:** The results conclude that the square shape is the most economical from the four tested basic shapes (4.2.1 "Shape"). In addition, the following were observed when building design was varied:

**Shape and Fenestration:** Maximizing glazing on south side increases cooling load on all shapes; adding up, however the savings incurring from solar gains in winter reduces the total energy load. More savings are concluded in the complex shapes (Tests: L2, Π2) although the rectangular shape allows more expansive window area.

**Shape and Mass:** Regarding mass, addition of it externally increases heating and cooling load on all shapes, where as addition of internal mass decreases both. Shapes accommodating large south window area, present higher amounts of energy savings.

**Insulation:** The introduction of insulation on the more complex shapes renders them more energy efficient. As for example addition of it on Π-shape upgrades it as the most economical from all other shapes.

#### 4.3.2 Mass

**Internal Mass:** The large diurnal temperature fluctuation in the island implies abundance of heat during the day, both in winter and summer and low temperatures at night. This renders the addition of internal mass effective in utilizing winter solar gains and the coolness of the summer nights.

**External Mass:** Addition of external mass increases energy load.

#### 4.3.3 Fenestration

Although it is concluded that fenestration is thermally a very sensitive, complex, many sided parameter which should be examined in conjunction to the entire building design, the following are observed.

**Orientation:** Avoiding east and west fenestration eliminates the potential of useful morning and afternoon solar gains which are desirable and beneficial for the thermal performance of the building. However summing up the savings



rendered by the reduction of cooling energy incurring by the elimination of overheating from east and west summer solar gains the yearly energy consumption is reduced. Maximizing South aspecting window is most advantageous.

**Shading:** Regardless orientation, permanent overhangs and extended walls limit useful solar gains. Movable shading devices however are advantageous due to their flexibility and intrinsically have the potential for controlled operation and therefore optimized performance.

**Ventilation and Infiltration Rate:** Controlling air infiltration rate, limits thermal losses in winter and heat gains in summer. This, combined with increased summer night ventilation, constitutes an effective measure in minimizing air conditioning energy load.

**Glazing Type:** Double glazing reduces heat losses in winter and consequently the total energy load.

#### 4.3.4 Insulation

The comparison of insulation with other passive design measures entailing no additional (*test no: RAd*) or little cost (*test RAe, RAc*) gives an indication of the cost effectiveness of the insulation. The final conclusions on insulation in conjunction with other parameters are summarized as follows:

**Shape:** The addition of insulation acts as the regulator of energy conservation on a geometrically complex building shape. This is at an additional cost and therefore the economic assessment of insulation should be viewed in conjunction with each shape variation of building.

**Thickness:** Energy consumption savings do not increase proportionably to the thickness increase. On the contrary there appears reduction of savings. The 50mm insulation thickness seems appropriate insulation level to be adopted in the process of minimizing energy load in the Cyprus house. The pay back period for the insulation of 50mm is the same as that of 25mm but has longer life span due to its bigger thickness. However further sensitivity studies are needed to define pattern of the effectiveness of the insulation thickness although the tests on thickness imply diminishing returns as the thickness of insulation is doubled or as it further increases.

**Stage of Introduction:** Comparison of insulation application on reference and improved design suggests that introduction of insulation on improved design is most effective. It seems that the combination of other design measures increases the effectiveness of insulation.

**Position of Insulation:** The positioning of insulation externally is derived as the



most effective for the climatological conditions of Cyprus.

**Extent of Insulation Application:** The roof is thermally the most vulnerable building component of the Cypriot house; this renders the application of insulation on the roof the most cost effective energy saving design measure. Extending insulation on the walls reduces the energy load, but at an additional cost. Whereas extending it on the floor the energy load increases.

#### **4.3.5 OTHER REMARKS**

It is further observed from the comparative studies and the analysis of the results that in establishing the "Zero Energy Houses" simulation profile, one could locate a region of the optimum design.

This optimum region offers various combinations of effective parameters resulting to "Zero Energy House". Specifically the combinations of the optimized effective variables of glazing orientation, additional internal mass and envelope insulation, in the four tested shapes reduced their useful energy consumptions between 95% and 97% (Tables: 4.1.2 to 4.1.5, test: R6, L6, Π6, S6). Furthermore, introduction of additional measures or refinement of these optimized variables on the Square-shape, selected to investigate the sensitivity of the effective parameters, also concluded to nearly zero energy profiles on tests between S6-S20 (Table 4.1.5). It is however important to incorporate in the design outline of the "Zero Energy House", such constructional characteristics so that it will have high market appeal and therefore should involve minimum departure from conventional construction. It should also be suitable for the life style of its inhabitants.

For this reason, in the process of establishing the design aspects for "Zero Energy Houses" the following chapters examine the role of the human factor, comment on the practical implications of the "Zero Energy" design and purpose design recommendations "Zero Energy House".



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## **CHAPTER 5**

### **THE ZERO ENERGY HOUSE AND THE OCCUPANTS**



## **5.0 THE ZERO ENERGY HOUSE AND THE OCCUPANTS**

The research so far has found that it is possible to achieve comfort conditions, for the Cyprus climate, without the need for mechanical energy for heating and cooling in houses, through the use of compact shape and the optimization of insulation, internal mass and fenestration design.

However, peoples' responses are a very important consideration in the creation of a zero energy house; but, the occupants desired comfort level is not a manipulable input factor; people react differently to the thermal environment; even when the optimum environment for a given activity level and clothing is produced not everyone is satisfied. Individuals themselves are not consistent and what is satisfactory one day may be uncomfortable another.

It became clear in the work that a more sophisticated analysis of buildings and user behaviour was necessary and this forms the main concern of this chapter.

From the building simulations and the analysis of the results in the previous chapter, it was found that the human element is instrumental in changing some of the assumed building characteristics by such simple acts as opening or closing doors, windows and shutters.

It was also found that the effects of the behaviour of the building and the users must be considered interdependently as it is the combined effect that is important.

Therefore, in the study of this chapter, the relative thermal effects of these parameters in various combinations in computer simulations, are to be considered to understand the qualitative behaviour of the building fabric in use. Parameters to be tested are:

- (I) Use of shutters for shading ( 5.1 "SHADING" )**
- (II) Opening and closing windows ( 5.2 "VENTILATION" )**

Also it is intended to investigate the possibility of introducing automatic shading and ventilating controls. This may lead to the optimal choice between different design alternatives based on flexibility, operational ease, and potential thermal efficiency.

As an integral part of the planning process, it is intended to recommend strategies which, by reducing the operational constraints currently imposed upon buildings, secure an optimized performance for "Zero Energy" houses in Cyprus.



## 5.1 SHADING

### General

In the previous chapter (4.0:"Results and Analysis") it has been concluded that the provision of shading devices is a very important fenestration parameter to combat overheating in the dwelling in the summer period (4.2.3.2 : "Shading"). It was also found that winter solar gains through fenestration reduce considerably (11%) fuel consumption for heating (4.2.3.1 : "Orientation and Glazing Area"). The optimized fenestration shading strategies are summed up as follows:

**Summer:** Shading between 07.00-19.00 hours.

**Winter:** Unobstructed solar access between 07.00-17.00hrs

However the introduction of manually operating shutters in order to provide summer solar control in occupied spaces (usual practice in Cyprus) may result in large energy penalties when misused by the occupants in either season to cause:

**In Summer:** Overheating when the shutters are left open during the day.

**In Winter:** Solar losses by sun blinding when shutters are left closed.

In this chapter the misuse of shutters, in both seasons (winter and summer), and the effect on indoor temperature in free running buildings are examined through computer simulations with thermal analysis program "Quick" (3.2.2.4). This is done in a series of combinations of sun control on fenestration for the "Zero Energy House" derived in previous chapters (4.3:"Summary and Conclusions").

### 5.1.0 SHADING - RESULTS AND DISCUSSION

#### Approach

This section presents and discusses the results obtained from building simulations of the "Zero Energy House" which have specific profiles of fenestration shading as their only variable and are modelled under free running conditions. The tested shading profiles are specified and outlined having as basis possible occupancy interference with the shading design objectives of the "Zero Energy House". These may range from maximum solar admission to total exclusion of direct radiation as a source of heat, depending on the season (Winter or summer). Thus the simulations of shading combinations are classified for the two seasons as follows:

#### Winter

In this series of simulations the effect of window shutters left closed during the day, contrary to the optimized fenestration winter strategy, and consequently the drop of indoor temperature is examined. The orientation of shaded windows is as follows:



**All unshaded**

**North windows shaded**

**North and West windows shaded**

**North, West and half of South window area shaded**

**All Shaded**

### **Summer**

In this series of simulations the effect of window shutters, left open during the day, contrary to the optimized fenestration summer strategy, on indoor temperature rise is examined. The orientation of windows left unshaded is as follows:

**All Shaded**

**Half area South fenestration unshaded**

**All South windows unshaded**

**South and West windows unshaded**

**All Unshaded**

The outline of window shading profiles of the building simulations and the effect on indoor temperature is tabulated in table 5.1. The discussion of the results follows the same order of the simulations as presented in the ranges for the two seasons as stated above ( 5.1.1 "Winter" and 5.1.2 "Summer"). The calculations from each simulation is analyzed in terms of its own entity and invites remarks derived from comparisons with the calculations from simulations of the other shading profiles. All simulations are also analyzed on the basis of comparing results of each shading profile with the optimized design strategy for that range ("All unshaded"- for winter and "All Shaded"- for summer).

The performance of the parameters is analyzed in the following clauses and their efficiency is compared with each other and with the optimized strategy for the winter and summer season. The effect of the parameters on the indoor temperature as well as the deviation from comfort conditions are assessed both in winter and summer. This is illustrated on tables and graphs (*Tables 5.1, 5.1.0 - 5.1.5, Graphs 5.1.0 - 5.1.5*). Particular shading patterns which appear problematic are identified in summaries for each season. Finally design strategies are recommended which by reducing the operational constraints of manually operated shading devices secure optimum performance of fenestration for the "Zero Energy House" in Cyprus.

#### **5.1.1 Winter Counter-Effective Human Intervention in Fenestration Shading Strategy**

The results from computer building simulations, of various shading profiles caused by unexpected occupant intervention with the solar aperture, other than the one specified for the "Zero Energy" house, are analyzed and assessed having as basis the optimum fenestration shading strategy for winter as defined below (5.1.1.0).



### 5.1.1.0 Optimized Fenestration Shading Strategy for Winter

The optimized fenestration strategy for winter, derived from the previous chapter of the study (4.2.3.2 "Shading"), is outlined as having all glazed area unshaded during the day time to obtain maximum solar gains and achieve comfort indoor conditions ( 18.6 - 20.6 degrees Centigrade. *Table 5.1.0*).

#### 5.1.1.1 North Window Shutters Shaded

If North window shutters (Area= $3.5\text{m}^2$ ) are left closed during the day in winter, the indoor temperature reduces by 0.1 to 0.2 degrees Centigrade (Table:5.1.1) i.e 1% to 1.5% departure from the temperature achieved in the optimized fenestration profile (*Table 5.1.0*). However the indoor temperature is maintained within the comfort range for winter (18.6-22.6 deg. celcius, *Chapter: 2.0 "Bioclimatic Analysis"*).

#### 5.1.1.2 North and West Window Shutters Shaded

When in addition to North window shutters, the West ones are left closed during winter days, an insignificant temperature of further reduction of 0.1 degrees Centigrade occurs, and that only at certain hours of the day of no obvious pattern (*Table 5.1.2*). The small extent of temperature reduction is attributed to:

**Orientation** – West orientated windows have no direct solar gains in winter.  
**Window Area** –The west window area amounts only to  $0.50\text{m}^2$ .

The indoor temperature is as above (5.1.1.1) maintained within comfort levels.

#### 5.1.1.3 North, West and Half South window Shutters Shaded

When in addition to North and West window shutters half South window area remains shaded during the day, an indoor temperature reduction of 4.0 to 5.0 degrees Centigrade incurs i.e 23% to 30%. This temperature drop, lowers the indoor temperature below comfort level by 2.0 to 5.2 degrees Centigrade (*Table:5.1.3*) . The largest drop, of 5.2 degrees Centigrade, occurs between 09.00 to 22.00 hours. This span of time is that receiving the most of direct solar gain followed by six hours in the evening, as the result of time lag. The rapid reduction of indoor temperature is expected due to:

<b>Orientation</b>	–	South facing windows invite large amounts of solar gains incident at small angles in winter. Thus interception of solar radiation on this orientation has direct effect on indoor temperature.
<b>Window Area</b>	–	The south glazing area with solar aperture is limited by $17.5\text{m}^2$ which is a considerable amount of glazing reduction and consequently solar gains.



#### 5.1.1.4 All Windows Shaded

When all windows remain shaded during winter days, indoor temperature decreases rapidly in the rate of 9.0 to 10.5 degrees Centigrade (*Table: 5.1.4*). The additional shaded window area is of equal extent (17.50m<sup>2</sup>) as in the previous shading window profile above (5.1.1.3) however the indoor temperature reduction in current profile is 1.0 degree more. This is expected as all glazed area is shaded and there is no solar access at all. The indoor temperature drops further by 4.0 degrees to its lowest levels which at certain hours (09.00 to 18.00) is even lower than outdoor temperature (*Table 5.1.4*).

#### 5.1.1.5 Concluding Remarks on Winter Shading Strategy

The results derived from building simulations, of window shading profiles in winter, indicate that if shutters remain closed on the north and west orientated fenestration, the reduction of solar gains and consequently the drop of indoor temperature is insignificant (0.1 to 0.2 deg. Celsius *Tables: 5.1.0, 5.1.1, 5.1.2*). This is mainly attributed to:

- Area** — The window area on North and West sides is limited.
- Orientation** — There is no direct solar incidence on these facades.

However if South facing glazing is left shaded, in winter, the solar losses are considerable; an area of 10% of shaded South orientated windows causes a reduction of indoor temperature by 2.0 degrees centigrade and reaches 10.0 degrees reduction as the shaded window area increases. The reduction is attributed to the large amounts of solar gains received by fenestration on this orientation, due to the low solar path and the small angles of incidence. This results to rapid deviation of indoor temperature from comfort levels (*Tables 5.1.3 and 5.1.4*).

When all windows are left closed the indoor temperature drops below outdoor temperature (*Table 5.1.4*).

The above results emphasise the sensitivity of the manually operated shading devices and the associated uncertainties which could hinder the successful performance of the design of the "Zero Energy House".

#### 5.1.2 Summer Counter-Effective Human Intervention in Fenestration Shading Strategy

The results from computer building simulations for the summer shading profiles are analyzed and assessed with the same procedure as for winter. The optimum fenestration profile for summer as defined below (5.1.2.1) is taken as the basis in these series of combinations.



### 5.1.2.1 Optimized Fenestration Shading Strategy for Summer

The optimized fenestration strategy for summer, derived in previous chapter of the study (4.2.3.2 "Shading"), is outlined as having all glazed area shaded during the day time to obtain minimum solar gains and hence comfort indoor conditions ranging between 23.3 - 25.4 degrees Centigrade (*Table 5.1.4*).

### 5.1.2.2 Half Area of South window Shutters Unshaded

When half of the south window area (17.5m<sup>2</sup>) is left unshaded during summer days the indoor temperature increases by 0.1 to 0.6 degrees Centigrade (*Table 5.1.3*). The small temperature rise seems out of proportion with the large extent of glazing area left unshaded but this is attributed to:

- Orientation** — South orientated windows have no direct solar insolation in the summer.
- Design** — The optimized design of overhangs and extended vertical walls for south glazing, derived and employed at an earlier stage of the study (4.2.3.2 "Shading"), shade the solar aperture from the high summer sun while permitting rays from the low winter sun; the optimized design does not leave much space for any further improvement for sun control.

The temperature rise which appears in the current simulation is attributed to the decrease of thermal resistance of windows due to the absence of shutters.

### 5.1.2.3 All South Window Area Unshaded

When all south window shutters are left unshaded during summer the indoor temperature increases at the same rate as above (0.1 to 0.5 degrees Centigrade. *Table 5.1.2 and 5.1.3*). This increase in temperature deviates from the ones succeeded with optimized design by 0.2 to 1.0 degrees Centigrade (*Table 5.1.4 and 5.1.2*). However the indoor temperature continues to range within comfort levels (23.5 to 26.5 degrees Centigrade). The maximum temperature rise (1.0 degree Centigrade) reached indoors occurs in the early afternoon and evening hours between 14.00-22.00 hours (*Tables 5.1.2 and 5.1.4*).

### 5.1.2.4 South and West Windows Unshaded

If in addition to south windows the shutters of west windows are left open during summer day the indoor temperature shows a further rise of 0.1 degree Centigrade only at certain hours of the day (*table 5.1.1*). The small increase is associated with the small West window area (0.50m<sup>2</sup>).



### 5.1.2.5 All window Shutters Unshaded

A similar rate of increase presented above (0.2 degrees) occurs when the glazed area (3.50m<sup>2</sup>) of north windows is left unshaded during the summer (*Table 5.1.0 and 5.1.1*). The indoor temperature is maintained within comfort levels (23.8-26.6 Degrees Celsius). Maximum temperature is reached in the afternoon and early evening hours (16.00-20.00 hours). The peak temperature reaches 26.6 degrees.

### 5.1.2.6 Concluding Remarks on Summer Shading Strategy

The results derived from building simulations, of window shading profiles in summer, indicate that if shutters remain open on the north and west orientated fenestration, the increase of solar gains and consequently the rise of indoor temperature is insignificant. This causes no deviation from comfort levels (0.1 to 0.2 deg centigrade. *Tables: 5.1.4, 5.1.3, 5.1.2 and 5.1.1*). This is mainly attributed to:

- Area** -The window area on North and West sides is limited.
- Orientation** -There is no direct solar incidence on these facades.

In case half of South facing glazing is left unshaded, in summer, the solar gains increase rising indoor temperature by 0.1 to 0.6 degrees centigrade and reaching 1.2 degrees increase as the unshaded window area extends to all South fenestration area. However, the temperature increase causes no deviation of indoor temperature from comfort levels (*Tables 5.1.2, 5.1.3 & 5.1.4*). this is attributed to two main reasons:

- Orientation** — South orientated windows have no direct solar insolation in the summer.
- Design** — The optimized design of overhangs and extended vertical walls for south glazing.

The above results indicate the effectiveness of the optimization of permanent shading devices.

## 5.1.3 CONCLUDING REMARKS ON SHADING STRATEGY

### General

The above study focuses on the analysis of fenestration shading devices and techniques which are developed previously (*4.1.3.2 "Shading"*), so as to reduce unwanted solar heat gains in the summer, without conflicting with beneficial ones in winter, as solar gains play opposite roles for heating and cooling in the climate of Cyprus. In the study , emphasis is given on occupancy intervention on manually operated shading devices.

For the study, characteristics of windows and shading devices, are specified in terms of geometry and physical dimensions in shading profiles, in simulations



of the "Zero Energy House". The intention is to describe synthetically how the quality level of the internal environment is affected in response to hypothetical occupant shutter use patterns. These accommodate possibilities of potential conflicts of the double role of solar gains and destructive interference with the effective performance of the "Zero Energy House".

Table 5.1 sums up the attempt to systematise various possible shading operations by occupants. It aims to illustrate the correlation between solar heat gains or losses resulting from such operations, for the two seasons, and the thermal performance of the "Zero Energy House". This is done in order to conclude optimum shading design strategies for maintaining comfort conditions in the building considering the operational aspects of shading techniques .

From the results it is evident that the occupants' interference and misuse of the manually operated window shutters could be counter-effective and might annul the optimized fenestration design for "Zero Energy House" concluded in the previous chapters of the study. The uncertainties associated with the shading variable and occupant behaviour can be large in occupied buildings. This occurs, where solar gains is a significant part of the design in achieving indoor comfort conditions without the need of mechanical energy, as in the case of the "Zero Energy House".

### Winter

The results explicitly indicate that the counter-effect of misused south window shutters could be of vital importance for the maintenance of internal thermal comfort level in winter.

Tables and graphs 5.1.0 to 5.1.4, in Appendix 5.1.0 show temperatures of ambient outdoor and indoor air. Table 5.1.0 portrays optimized design for winter, in which all shutters are open. It illustrates that while the ambient outdoor air temperature varies from 6.5 to 14.0 degrees Celsius, the swing in the inside temperature remains within the comfort zone, from 18.6 to 20.6 degrees only.

The other tables and graphs indicate a drop of indoor temperature ranging from 0.1 to 10.5 degrees Celsius, depending on the extent and orientation of window shutters left shut during the winter day. If all window shutters are left shut, the internal temperature drops below outdoor, by 0.1 to 4.0 degrees. The largest drop occurs mainly between 09.00 to 18.00 hours (*table 5.1.4*). These results point out the reliance of the "Zero Energy House" on solar gains.

Furthermore the small extent of deviation of temperature, incurring when shutters are left shut on the house elevations other than south, confirm the validity of the optimization of fenestration distribution and orientation on the "Zero Energy House".

### Summer

Table 5.1.4 also illustrates the optimized design strategy for summer, with all



shading shutters closed, when the outside temperature reaches a maximum of 35.0 degrees Celsius whilst the inside reaches only 25.5 degrees.

Examining the results of the counter-effective human intervention on the manually operated window shutter on the "all-shut" optimized shading profile for summer (*Table 5.1.4*), it is noted that this poses no significant conflict on solar control. Comparing the free thermal behaviour of the building under the optimized summer strategy (*Table 5.1.4 "All Fenestration Shaded"*), with the less than optimized (*Tables 5.1.3-5.1.0*), the rise 0.4 to 1.0 degree Celsius of internal temperature indicated for some configurations presents no serious problem. Even when all window shutters remain open during summer day the internal temperature does not deviate from the comfort zone. Over the complete period of investigation the deviation did not exceed 1.00 degree Celsius, indicating at least for the shading variable, the efficient performance of the fixed shading devices of overhangs and vertical extended walls on the southern orientations for the summer season. For both seasons, the results also emphasize the significant role of the optimization of:

- (i) **Fenestration distribution and orientation**
- (ii) **Permanent shading overhangs and vertical extended walls**

on the thermal performance of the "Zero Energy House". The sun spends very little time during the summer in front of the major fenestration area which faces south; its south passage is at high altitudes, so window design optimization of shading overhangs in conjunction with extended walls, allow effective shielding from direct solar radiation.

### **Final Comments**

The above observations show that although window shutters contribute to limiting thermal gains in the summer, by reducing indoor temperature up to 1.3 degrees Celsius (compare tables 5.1.4 and 5.1.0) their negative effects of misusing them in winter might defeat the optimized performance of the "Zero Energy House" to the extent of dropping indoor temperature below outdoor during winter (*Table 5.1.4*).

The results also indicate that the combined effect of the optimum design of fenestration orientation and permanent shading devices provide sufficient sun control without the need of the manually operated shutters and its possible counter-effects.

Even so, if design fenestration aspects such as orientation, size, distribution, and sun control devices, differ to those developed for the "Zero Energy House", the application of shutters for shading could be the only solution. For example, the fixed overhangs do not work for windows facing east or west, since the sun is low in the sky in the morning and afternoon. In such cases the introduction of automatic controls is imperative in order to eliminate the negative effects of the manually operated shutters misuse presented above.



TABLE 5.1 : SHADING FENESTRATION PROFILES FOR WINTER AND SUMMER EFFECT ON INDOOR TEMPERATURE

Table No. Code	WINDOW SHUTTERS			INDOOR TEMPERATURE °C		
	Orientation	Area(m²)	Strategy	Average T	Ave. Deviation'	Deviation Range
WINTER DAY BETWEEN 07.00-19.00 HOURS						
5.1.0 HO_BASE	South West North	35.00 0.50 3.50	Open Open Open	19.70	BASE Winter Optimal	0.0 - 0.0
5.1.1 SHAD_NORTH	South West North	35.00 0.50 3.50	Open Open Closed	19.55	- 0.15	0.1 - 0.2
5.1.2 SHAD_N-W	South West North	35.00 0.50 3.50	Open Closed Closed	19.50	- 0.20	0.2 - 0.3
5.1.3 SHAD_NWS1/2	South South West North	17.50 17.50 0.50 3.50	Open Closed Closed Closed	14.96	- 4.74	4.3 - 5.2
5.1.4 SHAD_ALL	South West North	35.00 0.50 3.50	Closed Closed Closed	10.03	- 9.67	8.9 - 10.5
SUMMER DAY BETWEEN 07.00-19.00 HOURS						
5.1.4 SHAD_ALL	South West North	35.00 0.50 3.50	Closed Closed Closed	24.7	BASE Summer Optimal	0.0 - 0.0
5.1.3 SHAD_NWS1/2	South South West North	17.50 17.50 0.50 3.50	Open Closed Closed Closed	25.13	+ 0.43	0.1 - 0.6
5.1.2 SHAD_N-W	South West North	35.00 0.50 3.50	Open Closed Closed	25.46	+ 0.76	0.2 - 1.1
5.1.1 SHAD_NORTH	South West North	35.00 0.50 3.50	Open Open Closed	25.49	+ 0.79	0.2 - 1.2
5.1.0 HO_BASE	South West North	35.00 0.50 3.50	Open Open Open	25.57	0.87	0.2 - 1.3

\* Deviation: Deviation from BASE i.e. indoor Temperature of "ZERO HOUSE"  
+: Indicates increase of Temperature  
-: Indicates decrease of Temperature



## 5.2 VENTILATION AND INFILTRATION

### General

In the previous chapter (4.0 "Results and Analysis") it was found that the combination of controlled infiltration rate in both winter and summer days ( $0.5 \text{ ac/h}$ ) and increased ventilation in the summer nights ( $10 \text{ ac/h}$ ) results to the significant reduction of cooling and heating load of 32% (4.1.3.3 "Infiltration Rate and Ventilation"). The adopted infiltration rate of  $0.5 \text{ ac/h}$  assumes good weather stripping, whereas the increased ventilation value of  $10 \text{ ac/h}$  assumes encouraged airflow through window apertures. The optimized infiltration and ventilation strategies are summed up as follows:

**Summer Nights:**      **All Windows Open for Maximum Ventilation**

**Summer Days :**      **All Windows Closed for minimum Heat Gain**

**Winter :**      **All Windows Closed for minimum Heat Loss**

However the manually operated purpose openings for the provision of ventilation, may result in large energy penalties when misused by the occupants in either season to cause:

**In Summer :** Overheating when windows are left open during the day or closed during the nights.

**In Winter :** Heat losses when windows are left open during the days or nights

In this chapter the misuse of openings, in both seasons (winter and summer), and the effect on indoor temperature in free running buildings are examined through computer simulations with thermal analysis program "AGRELEK" (3.2.2.4). This is done in a series of combinations of open windows on the "Zero Energy House" derived in previous chapters (4.3: "Outline of Zero Energy House"). The programme used for the simulations has the facility to calculate either the infiltration or ventilation rates.

Infiltration is defined as the unintentional airflow through background leakage areas. The infiltration rate per hour is calculated in the programme with an empirically derived equation by specifying the building type as either "leaky", "standard" or "tight" building. "Standard" building is considered in the programme the building in which no special care was taken to seal small openings that may exist under doors and in window frames. This is typically the one chosen for the current simulations. A "leaky" building would be a building where gaps may exist between the roof and the walls or where pipes and cables enter the building. A "tight" building would be one in which special care was taken to seal all openings.

Ventilation refers to the replacement of indoor air with outside air. In the simulations is taken as the intentional airflow through purpose provided



openings such as windows and ventilators and is calculated with a detailed numerical analysis procedure. The area and height above ground level of each opening is specified for the different ventilation periods during the 24 hour day. The maximum height of the roof of the building is also considered in the calculations. The prediction of ventilation rates is made by the programme and consequently the effect on indoor temperature is calculated.

Before discussing the simulations two general comments about the programme must be born in mind:

- (a) The ventilation prediction model incorporated in the programme is only stack driven. In other words at least two openings at different heights are required before any significant ventilation is achieved. The other driving function, namely wind effect, is ignored since the worst-case scenario is assumed to be windless days. During these windless days only openings at different heights can result in significant ventilation.
- (b) The incorporated infiltration model only depends on the difference between the inside and outside temperatures and is thus different from the ventilation model. At small air change rates, typically when all openings are at the same height, inconsistent results are thus possible when switching between the ventilation model and the infiltration model. For example it is possible that the air change rates predicted by the ventilation model for a single small window are lower than the air change rates predicted by the infiltration model for closed windows. Fortunately the influence of these inconsistencies is very small and can usually for practical purposes be ignored.

## **5.2.0 VENTILATION AND INFILTRATION - RESULTS AND DISCUSSION**

### **Approach**

This section presents and discusses the results obtained from building simulations of the "Zero Energy House" which have specific profiles of fenestration for ventilation and infiltration rates as their only variable and are modelled under free running conditions. The tested ventilation and infiltration profiles, result from opening and closing the windows and are specified and outlined having as basis possible occupancy interference with the ventilation and infiltration design objectives of the "Zero

Energy House". These may range from maximum intentional airflow to an airtight profile depending on the season (winter or summer) and period (day or night). The simulations of purpose windows are classified in two major series:

### **Summer Night Ventilation**

### **Summer Days and Winter Infiltration and Ventilation**

Both series of simulations have as reference the concluded "Zero Energy House"



profile. This is the optimum design and it embodies ideal summer ventilation, as well as winter infiltration for indoor comfort conditions.

The two series are outlined as follows:

### **Summer Nights**

In this series of simulations the effect of window area left closed during summer nights (contrary to the optimized fenestration summer nights strategy) and consequently the increase of indoor temperature is examined. The combinations of windows left closed and the effect on indoor temperature is tabulated on table 5.2.1.

### **Summer Days - Winter Nights and Days**

In this series of simulations the effect of window area left open during summer days and during winter (contrary to the optimized fenestration infiltration strategy), on the indoor temperature rise in summer and drop in winter, is examined. The combinations of windows left open and the effect on indoor temperature is tabulated on table 5.2.2

In the simulation series the human intervention in the ideal use of windows for optimum ventilation and infiltration rates, is studied in three counter-active patterns as follows:

- **Counter-Effective Intervention in Summer Ventilation.**
- **Counter-Effective Intervention in Preventing Summer Heat Gains.**
- **Counter-Effective Intervention in Preventing Winter Heat Losses.**

The discussion of the results follows the same order of the simulations as presented in the three ranges of counter-effective human intervention for the two seasons as titled above and analyzed below in clauses 5.2.1 and 5.2.2 for Summer, 5.2.3 for winter.

The calculations from each simulation is analyzed in terms of its own entity and invites remarks derived from comparisons with the calculations from simulations of the other combinations of open windows. All simulations are also analyzed on the basis of comparing results of each window profile with the optimized design strategy for that range (All Windows

Open in Summer Nights - All Windows Closed in Summer Days and Winter).

The performance of the parameters is analyzed in the following clauses and their efficiency is compared with each other and with the optimized strategy for the winter and summer season. The effect of the parameters on the indoor temperature as well as the deviation from comfort conditions are assessed both in winter and summer. This is illustrated on tables and graphs ( 5.2.1 - 5.2.5). Particular window patterns which appear problematic are identified in summaries for each season.



Finally design strategies are recommended which by reducing the operational constraints of manually operated windows secure optimum performance of natural ventilation and infiltration for the "Zero Energy House" in Cyprus.

### **5.2.1 Counter-Effective Intervention in Summer Nights Ventilation**

This section presents the results derived from computer building simulations of various ventilation profiles caused by unexpected occupant intervention with maximum airflow, other than the one specified for the "Zero Energy House" during summer nights. These are also analyzed and assessed having as basis the optimum ventilation rates for summer nights as defined below (5.2.1.0).

The summer night ventilation profiles differ in these series in terms of area and height of windows left closed during summer nights between 22.00-06.00 hours. The open window area, at varying heights, is decreased as the tests develop from the ideal to the less than ideal ventilation range (*tables nos: 5.2.1.0 - 5.2.1.8*). The height is taken from ground level up to the lower level of window. The effect of summer night ventilation on indoor temperature is studied in the following clauses.

#### **5.2.1.0 Optimized Ventilation Strategy for Summer Nights All Windows open - 40.0m<sup>2</sup>**

The optimized ventilation strategy for summer nights derived from the previous chapter of the study (4.2.3.3 "Infiltration Rate and Ventilation") is outlined as having all windows open during nights to obtain maximum ventilation rates for cooling down the building structure. (*Table:5.2.1.0*).

#### **5.2.1.1 Bathroom Window (Area=1m sq. at 1m height) - Closed**

In this test the open window area for summer night ventilation decreases by 1 square meter from the optimized profile above. However when comparing this test (*no:5.2.1.1*) with the optimized test (*no: 5.2.1.0*) in table 5.2.1, is observed that an unexpected reduction of 0.1 degrees centigrade appears. This is due to the fact that the air change rates predicted by the ventilation model for a single small window are lower than the air change rates predicted by the infiltration model for closed window (See comment (b) in 5.2 "Ventilation and Infiltration"). Therefore this insignificant temperature decrease can be disregarded.

#### **5.2.1.2 Closed Window Area Kitchen and Bathroom Windows - 3.5m<sup>2</sup>**

A small increase of 0.2 degree centigrade on indoor temperature incurs on base-case when the additional kitchen window area of 2.7 sq.meters closes on the ground floor at 1m height (Compare tests, graphs and table nos:5.2.1.0 and 5.2.1.2). With such a small increase, the indoor temperature does not depart from the comfort range achieved in the optimized ventilation profile (*Table 5.2.1.0*).



### **5.2.1.3 Closed Window Area One Living-room, Kitchen and Bathroom Window 12.5m<sup>2</sup>**

When on the above closed window area the bedroom window area of 8.80 sq.meters on upper floor (at 4.00 meters height) is added, the indoor temperature further increases by 0.5 degrees (compare tests and tables nos: 5.2.1.2 with 5.2.1.3 on table 5.2.1).

However even with this increase the indoor temperature is maintained within the comfort range for summer (24.1 - 26.9 degrees. *Table 5.2.1.3*).

### **5.2.1.4 Closed Window Area Two Living-room, Kitchen and Bathroom Windows 17.5m<sup>2</sup>**

A reduction of open window area by half the window area (4.40sq. meters) in the previous simulation (*Test no: 5.2.1.3*) and at the same height (at 4.00 meters) rises the indoor temperature by 0.65 degrees. This is a larger increase than anticipated (compare tests, graphs and tables nos: 5.2.1.2 and 5.2.1.3 with 5.2.1.3 and 5.2.1.4).

The results of this simulation indicate that the increase of indoor temperature is not linearly proportional to the reduction of open window area. Also although the indoor temperature rises it is still maintained within comfort level (*table no:5.2.2.4*).

### **5.2.1.5 Closed Window Area All Ground Floor Windows - 22.5m<sup>2</sup>**

In test no:5.2.1.5 all open window area on ground floor is closed. The reduction of the window open area amounts to the same extent as between tests nos:5.2.1.3 and 5.2.1.4. However the indoor temperature increases by 5.0 degrees. This is a considerable temperature rise which deviates indoor temperature from the comfort range to the temperature range of 31.1-32.2 degrees (*table: 5.2.1.5*).

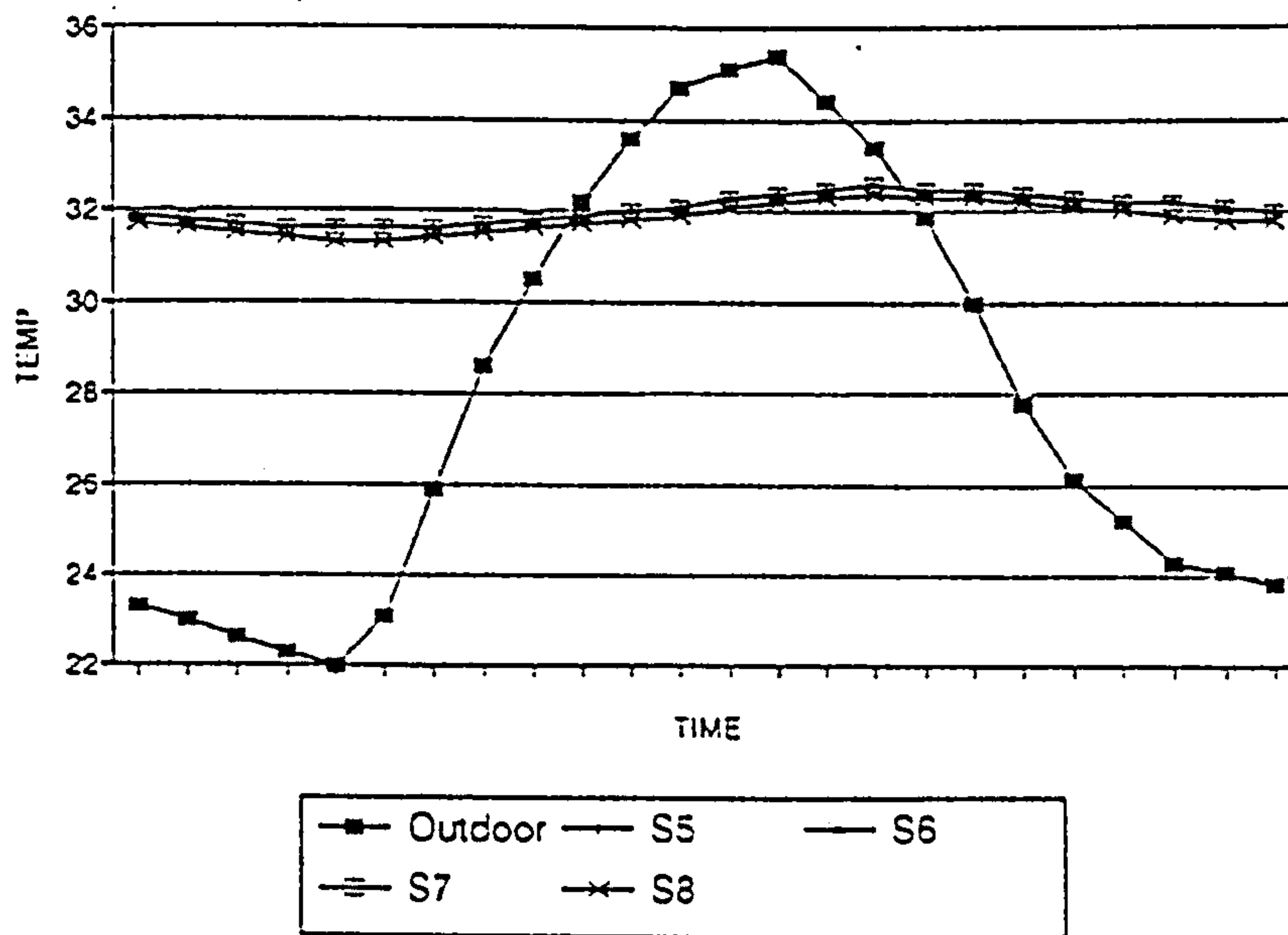
The results from this test show that the elimination of all open window area at one level ceases significant ventilation, since only openings at different heights can result to stack effect and therefore significant ventilation rates (see comment (a) in 5.2 "Ventilation and Infiltration").

### **5.2.1.6 Closed Window Area One Bedroom and All Ground Floor Windows -30.0m<sup>2</sup>**

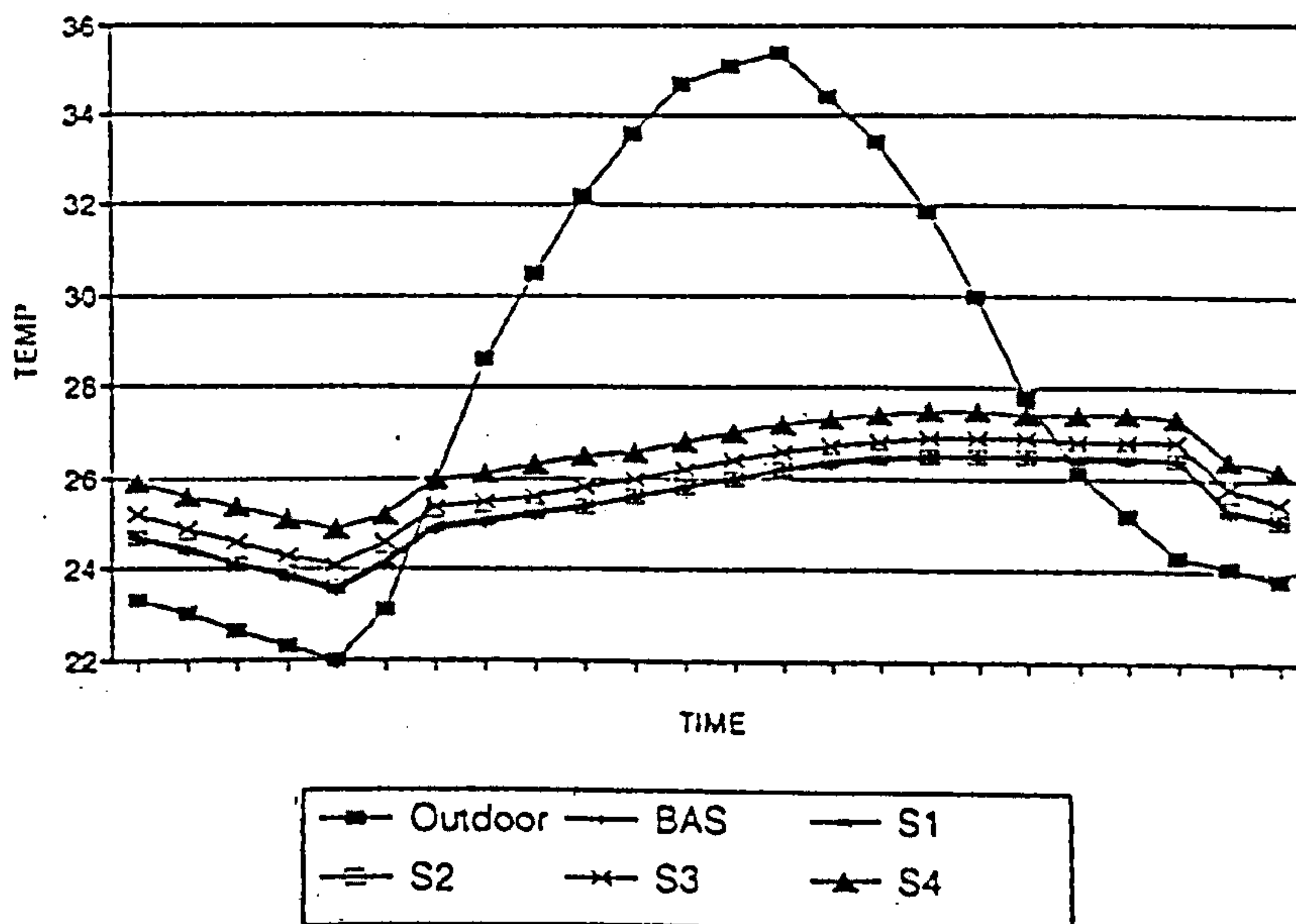
A further increase of the closed window area of 8.80m<sup>2</sup> on the upper floor causes no alteration on the indoor temperature (*test, graph and table no:5.2.1.6*).



GRAPH 5.2.2 A - SUMMER NIGHT VENTILATION  
WINDOWS ON SINGLE LEVEL ONLY



GRAPH 5.2.1 A - SUMMER NIGHT VENTILATION  
WINDOWS ON DIFFERENT LEVELS





### **5.2.1.7 Closed Window Area Two Bedroom and All Ground Floor Windows - 35m<sup>2</sup>**

As above, an additional increase of closed window area of 8.80 square meters on the upper floor causes no alteration on the indoor temperature (*test, graph and table no:5.2.1.7*).

The results from the last two tests imply that the temperature range concluded in test no: 5.2.1.5, by closing all openings on ground floor, is the maximum that can be reached inside the "Zero Energy House".

### **5.2.1.8 Closed Window Area All Windows -40.0m<sup>2</sup>**

An unexpected Temperature reduction of 0.2 degrees incurs if all windows remain closed during summer night (*test, graph and table no: 5.2.1.8*). This is due to the fact that the specified infiltration model for "standard buildings" predicts higher air change rates than the ventilation model used in tests nos:5.2.1.5 - 5.2.1.7, see comment (b) in 5.2 .

### **5.2.1.9 Concluding Remarks on Summer-Night Ventilation Strategy**

On graph no:5.2.1, the predicted temperatures of the results from test nos: 5.2.1.1 to 5.2.1.4 indicate that a significant amount of ventilation is achieved in all these tests, even after the closing of certain window area. Test nos: 5.2.1.1 and 5.2.1.2 show almost no difference from the base case because the eliminated window areas in both cases are relatively small. The more significant reduction of window area in tests nos: 5.2.1.3 and 5.2.1.4 gradually restricts ventilation and consequently temperatures increase. The increase in temperature is however not linearly proportional to the reduction in window area. As open window area decreases the changes become more critical.

The results from test nos:5.2.1.5 to 5.2.1.8 are shown in figure 5.2.2. Clearly the ventilation rates are insignificant for all cases, irrespective of window area and consequently indoor temperature rises above comfort level. The reason for this is that all remaining open window areas are at the same height, see comment (a) in 5.2. The small unexpected reduction in temperatures (0.2 degrees) when closing all the windows in case 5.2.1.8 is due to the fact that the specified infiltration model for "standard buildings" predicts higher air change rates than the ventilation model used in tests 5.2.1.5 to 5.2.1.7, see comment (b) in 5.2. For all practical purposes this reduction in temperatures can be disregarded.

The analysis of the above results, from this series of simulations, lead to the testing of an additional ventilation profile. This is in an effort to derive strategies for the reduction of the operational constraints in summer night ventilation (*Test no:5.2.1.9*).

The test examines the possibility of maintaining comfort conditions throughout the day by keeping, at least, two open window areas on different levels during night. From the test is found that an open window area of 1.0 square meter at



levels 1m and 0.8m height, between 22.00-06.00 hours, maintains indoor temperature near comfort conditions during the 24 hour period (27.6-29.2 degrees. *Table and graph 5.2.1.9*).

## **5.2.2 Counter-Effective Intervention in Summer Day Ventilation**

This section presents the results from computer building simulations of various ventilation profiles caused by unexpected occupant intervention with minimum airflow strategy, during summer days, other than the one specified for the "Zero Energy House". These are also analyzed and assessed having as basis the optimum infiltration rates for summer days defined below (5.2.2.0).

The ventilation profiles for summer days differ in these series in terms of area and height of windows left open during summer days (between 06.00-22.00 hrs). The open window area, at varying heights, is increased as the tests develop from the ideal (all windows closed) to the less than ideal infiltration rates (*Table:5.2.2 nos: 5.2.2.0 - 5.2.2.25*). The effect of infiltration and ventilation on indoor temperature, during summer days, is studied in the following clauses.

### **5.2.2.0 Optimized Infiltration-Ventilation Strategy for Summer days**

The optimized infiltration/ventilation strategy for summer days derived from previous chapter of the study (4.1.3.3 "Infiltration Rate and Ventilation") is outlined as having all windows closed during days to obtain minimum airflow in the house and therefore avoid heat gains. (*Table:5.2.2.0*).

#### **5.2.2.1 Open Windows during Summer Days**

The tests in this series of simulations range in terms of increasing the open window area from all windows closed (ideal case) to all windows open during summer days. They are classified in six groups according to the extent of window area left open. The indoor temperature variation is analyzed from the results as follows:

- (i) **Open Window Area 0- 3.5 m<sup>2</sup>** : The indoor temperature does not alter up to this extent of open window area during summer days (*tables: 5.2.2.1-5.2.2.15*).
- (ii) **Open Window Area - 3.5 m<sup>2</sup>** : This extent of open window area during summer day causes an insignificant indoor temperature rise of up to 0.1 degree only. The indoor temperature ranges from 23.4 to 26.7 degrees (*Tables: 5.2.2.16-5.2.2.18*).
- (iii) **Open Window Area - 7.5 m<sup>2</sup>** : Doubling the extent of open window area specified in (ii) also doubles the indoor temperature rise to 0.2 degree. The indoor temperature ranges from 23.5 to 26.8 degrees (*Tables: 5.2.2.19-5.2.2.21*).



**Table 5.2.1 HOUSE SIMULATIONS FOR SUMMER NIGHT VENTILATION  
(HOURS 22.00-06.00)**

TEST		WINDOWS (OPEN)			INDOOR TEMPERATURE	
NUMBER	NAME	AREA (m <sup>2</sup> )	HEIGHT (m)	DESCRIPTION	RANGE (°C)	COMFORT HOURS
5.2.1.0	VENT-BAS	17.6 17.6 2.7 1.0	0.8 4.0 1.0 1.0	All windows open for maximum night ventilation	23.4-26.6	ALL HOURS
5.2.1.1	VENT-S1	17.6 17.6 2.7	0.8 4.0 1.0	Bathroom window closed	23.6-26.5	ALL HOURS T-decreases 0.15°C all hrs except 22.0-6.00
5.2.1.2	VENT-S2	17.6 17.6	0.8 4.0	Bathroom & kitchen windows closed	23.6-26.8	ALL HOURS T-Increase 0.1°C Hrs
5.2.1.3	VENT-S3	17.6 8.8	0.8 4.0	Bathroom & kitchen & LR1/2 windows closed	24.1-26.9	ALL HOURS T-Increase 0.5°C Hrs 01.00-05.00 0.4°C other
5.2.1.4	VENT-S4	17.6 4.4	0.8 4.0	Bth & Kit & LR windows closed	24.9-27.5	ALL HOURS T-Increase 0.65°C
5.2.1.5	VENT-S5	17.6	0.8	Bth & Kit & LR windows closed	31.6-32.6	NONE T-Increase 5°C
5.2.1.6	VENT-S6	8.8	0.8	Bth & Kit & LR & Br1/2 windows closed	31.6-32.6	NONE No-T.alteration
5.2.1.7	VENT-S7	4.4	0.8	Bth & Kit & LR & 1Brm windows closed	31.6-32.6	NONE No-T alteration
5.2.1.8	VENT-S8	0	0	All windows closed	31.3-32.4	NONE (T-Increase 0.2°C after 06.00Hrs)
5.2.1.9	VE-SW-1a	1.0 1.0	0.8 5.0	Lr & Kit windows open	27.6-29.2	ALL HOURS
5.2.1.10	VE-SW-2	1.0 1.0	0.8 5.0	Lr & Kit windows open 00.00-24.00 hours	28.1-30.3	22.00-10.00
5.2.1.11	VE-SW1-1	1.0 1.0	1.0 5.0	Lr & Kit open 06.00-22.00 hours All open 22.00-06.00	23.8-28.0	ALL HOURS
5.2.1.12	VE-SW1-3	1.0 1.0	0.8 5.0	2m <sup>2</sup> open 06.00-22.00 ALL CLOSED 22.00-06.00	31.0-32.0	NONE

**Notes:**

- (i) For the above tests, in Summer days and winter, infiltration rate is specified that for a standard building and is calculated by the programme.
- (ii) All windows are assumed closed during closed the day (06.00-22.00 hours)
- (iii) The open window area specified for each test is assumed open between 22.00-06.00 hours.
- (iv) The above notes do not apply for test nos: 5.2.1.10, 5.2.1.11 and 5.2.1.12. For these tests the hours are specified in the description of each test.



**(iv) Open Window Area - 17.50 m<sup>2</sup>** : Increasing the extent of open window area during summer day increases the indoor temperature by 0.4 degree. The indoor temperature ranges from 23.5 to 27.0 degrees (*Tables: 5.2.2.22-5.2.2.23*).

**(v) Open Window Area - 35.00 m<sup>2</sup>** : Doubling the above open window area during summer day also doubles the indoor temperature rise to 0.8 degree. The indoor temperature ranges from 24.1 to 27.4 degrees (*Table: 5.2.2.24*).

**(vi) Open Window Area - All = 40.00 m<sup>2</sup>** : If all window area is left open during summer day the indoor temperature rises to 1.0 degree. The indoor temperature ranges from 24.1 to 27.5 degrees (*Table: 5.2.2.25*).

In all above tests the indoor temperature is maintained within comfort conditions.

#### **5.2.2.2 Concluding Remarks on Summer Days Ventilation Strategy**

The results derived from building simulations, of varying open window area during summer days, indicate that only extensive open window area (35.00 sq.meters and over) result to significant indoor temperature rise (0.8 degrees centigrade). This causes no deviation from comfort levels not even when all windows are left open during summer days (40.00sq.meters of open windows rises indoor temperature by 1.0 degree). This could be mainly attributed to either:

**(i) Large Diurnal Temperature Fluctuations:** The outdoor temperature drops by 15.5 degrees during summer nights (*Table:5.2.0*). The low night temperature is utilized and cools the building indoors.

**(ii) Building Structure:** The optimized internal mass of the "Zero Energy House" (4.1.2:"Mass"), combined with the diurnal temperature fluctuation (see (i) above), offer the potential to the building structure to receive and retain the incoming heat during the summer day and dissipate it in the cool night. This results to the small variation in the interior temperature which amounts only to 2.5 degrees. The indoor temperature attenuation is considerable when compared with outdoor temperature swing of 15.5 degrees.

**(iii) Night Ventilation:** Ventilating the building structure during summer nights by deliberately opening up all windows forms a fixed parameter in all the tests of this series and contributes to the cooling of the building structure. The adverse effect of closing window areas, during summer nights is analyzed in 5.2.1 "Counter-Effective Intervention in Summer Night Ventilation". The significance of night ventilation is obvious when comparing tests of the same open area during day but having all windows closed at night (compare test no: 5.2.2.15 with 5.2.1.12). When all windows are closed at night the indoor temperature reaches its highest values. These are the same as recorded in the worse scenario of counter-effective intervention in summer night ventilation (*Table: 5.2.1 tests:5.2.1.5-5.2.1.8*).

**(iv) Shading:** The adoption of fixed shading devices in the "Zero Energy House", such as overhangs and extended walls, intercept the summer sun and keep all the glazed surfaces well shaded and therefore the building structure cool.



**Table 5.2.2: HOUSE SIMULATIONS - INFILTRATION/VENTILATION**  
**SUMMER DAYS (06.00-22.00 Hours)**  
**WINTER DAYS (00.00-24.00 Hours)**

TEST		OPEN WINDOWS			INDOOR TEMPERATURE	
NUMBER	NAME	AREA (m <sup>2</sup> )	ASPECT	HEIGHT (m)	RANGE (°C)	COMFORT HOURS
5.2.2.0	VENT-BAS	0	-	-	W=18.1-19.9 S=23.4-26.6	W=ALL HOURS S=ALL HOURS
5.2.2.1	VENT-IA	1.0	SOUTH	1.0	W=17.9-19.8 S=23.4-26.6	W=ALL HOURS S=ALL HOURS
5.2.2.2	VENT-NOR	1.0	NORTH	1.0	W=17.9-19.7 S=23.4-26.6	W=ALL HOURS S=ALL HOURS
5.2.2.3	VE-WO-2	0.5 0.5	SOUTH NORTH	0.2 1.0	W=16.9-18.8 S=23.4-26.6	W=10.00-22.00 S=ALL HOURS
5.2.2.4	VE-WBO-2	0.5 0.5	NORTH WEST	1.0 6.0	W=15.6-17.7 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.5	VE-WBO-3	0.5 0.5	NORTH NORTH	1.0 6.0	W=15.6-17.7 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.6	VE-WAO-1	0.5 0.5	SOUTH WEST	0.2 0.6	W=15.5-17.6 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.7	VE-WAO-2	0.5 0.5	SOUTH SOUTH	0.2 0.6	W=15.5-17.7 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.8	VENT-WBA	1.0 0.5	NORTH WEST	1.0 6.0	W=15.2-17.3 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.9	VENT-WBB	1.0 0.5	NORTH WEST	0.2 6.0	W=15.0-17.2 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.10	VENT-WAI	1.0 0.5	SOUTH WEST	0.2 6.0	W=15.0-17.2 S=23.4-26.6	W=NONE S=ALL HOURS
5.2.2.11	VENT-WI	2.0	NORTH	1.0	W=17.7-19.5 S=23.4-26.6	W=ALL HOURS S=ALL HOURS
5.2.2.12	VENT-WI-1	2.0	SOUTH	1.0	W=17.7-19.5 S=23.4-26.6	W=ALL HOURS S=ALL HOURS
5.2.2.13	VENT-W2	1.0 1.0	SOUTH NORTH	1.0 1.0	W=17.6-19.4 S=23.4-26.7	W=07.00-03.00 S=ALL HOURS
5.2.2.14	VENT-WIA	1.0 1.0	SOUTH NORTH	0.2 1.0	W=15.8-17.9 S=23.4-26.7	W=NONE S=ALL HOURS
5.2.2.15	VENT-WIA-1	1.0 1.0	SOUTH NORTH	0.2 5.0	W=14.3-16.6 S=23.4-26.7	W=NONE S=ALL HOURS
5.2.2.16	VENT-WA4	3.5	SOUTH	0.2	W=17.2-19.1 S=23.4-26.7	W=09.00-24.00 S=ALL
5.2.2.17	VENT-WB4	3.5	NORTH	1.0	W=17.1-18.9 S=23.4-26.7	W=09.00-24.00 S=ALL



TEST		OPEN WINDOWS			INDOOR TEMPERATURE	
NUMBER	NAME	AREA (m <sup>2</sup> )	ASPECT	HEIGHT (m)	RANGE (°C)	COMFORT HOURS
5.2.2.18	VENT-W4	1.0 2.5	SOUTH NORTH	0.2 1.0	W=15.1-17.2 S=23.5-26.8	W=NONE S=ALL
5.2.2.19	VENT-WA5	7.5	SOUTH	0.2	W=16.4-18.2 S=23.5-26.8	W=10.00-22.00 S=ALL
5.2.2.20	VENT-WA5-1	7.5	NORTH	0.2	W=16.1-17.8 S=23.4-26.8	W=NONE S=ALL HOURS
5.2.2.21	VENT-WA6	3.5 4.0	NORTH NORTH	1.0 5.0	W=11.4-14.5 S=23.4-26.8	W=NONE S=ALL HOURS
5.2.2.22	VENT-WA7-1	17.5	SOUTH	0.2	W=14.8-16.7 S=23.4-27.1	W=NONE S=ALL HOURS
5.2.2.23	VENT-WA7	10.0 7.5	SOUTH SOUTH	0.2 5.0	W=9.7-13.6 S=23.5-27.0	W=NONE S=ALL HOURS
5.2.2.24	VENT-WA8	17.5 17.5	SOUTH SOUTH	0.2 5.0	W= 8.7-13.4 S=23.5-27.4	W=NONE S=ALL HOURS
5.2.2.25	VENT-WA9	17.5 17.5 3.5 4.0 0.5	SOUTH SOUTH NORTH NORTH WEST	0.2 5.0 1.0 5.0 6.0	W= 8.5-13.4 S=23.5-27.5	W=NONE S=ALL HOURS

**Note:** For the above tests for summer night ventilation  
(between 22.00-06.00 Hours) all windows are assumed open.



It is further observed in the tests that the variables of orientation and height of the open window area does not effect the indoor temperature (compare *tables: 5.2.2.13 and 5.2.2.14,.15 and table 5.2.2.11 with 5.2.2.12 and 5.2.2.13*). It is assumed that the benefit of cooling resulting from temperature moderators described above in (i)-(iii), prevails the stack effect incurring from windows at different heights as well as the heat gains due to different orientation. Absence of the above measures cause indoor temperature rise from the indrawn hot air during the summer day (see above (iii) Night Ventilation).

It is also noted that the indoor temperature increase is proportional to the window area and occurs mainly between 06.00-22.00 hours. These two aspects of indoor temperature are related to the input changed data, of the window test profiles, regarding characteristics of the glazed surfaces. The values of transmittance, absorbance, emissivity and thermal conductivity of window areas alter when open and the effect is reflected on the indoor heat gains.

The above results indicate that the concluded strategy for the "Zero Energy House" of closing all windows during summer days, keeps indoor temperature by 1.0 degree lower than assuming the worse-case scenario of opening all windows. However even during this most counter-effective intervention in the summer day ventilation strategy, indoor comfort conditions are maintained. This confirms the validity of the optimization of the building structure and the summer night ventilation strategy of the "Zero Energy House" to which the lingering of the night cooling effect is attributed. Nevertheless, if windows are kept closed at night, an area of 2.0 square meters is enough to raise indoor temperature to 32.0 degrees indoors (*test no:5.2.1.12*).

### **5.2.3 Counter-Effective Intervention In Winter Infiltration Strategy**

This section presents the results from computer building simulations of various ventilation profiles caused by unexpected occupant intervention with minimum airflow strategy, during winter days, other than the one specified for the "Zero Energy House" for the winter season. These are also analyzed and assessed having as basis the optimum infiltration rates for winter days defined below (*5.2.2.0*).

The ventilation profiles for winter days differ in these series in terms of area and height of windows left open during winter days (between 00.00-24.00 hours). The open window area, at varying heights, is increased as the tests develop from the ideal (all windows closed) to the less than ideal infiltration rates (*Table:5.2.2 nos: 5.2.2.0 - 5.2.2.25*). The effect of infiltration and ventilation on indoor temperature, during winter, is studied in the following clauses.

#### **5.2.3.0 Optimized Infiltration-Ventilation Strategy for Winter**

The optimized infiltration/ventilation strategy for winter days derived from previous chapter of the study (**4.1.3.3 "Infiltration Rate and Ventilation"**) is outlined as having all windows closed throughout the day to obtain minimum



airflow in the house and therefore avoid heat losses. (*Table:5.2.2.0*).

### 5.2.3.1 Open Windows during Winter Days

The tests in this series of simulations range in terms of increasing the open window area from all windows closed (ideal case) to all windows open during winter days (00.00-24.00 hours). They are classified in six groups according to the extent of window area left open. Each group is analyzed in respect of height and orientation and their effect on indoor temperature as follows:

**(I) Open Window Area 0-3.5 m<sup>2</sup> :** A window area up to 3.5m<sup>2</sup> left open during winter has varied effect on indoor temperature depending on the level of the openings and their orientation. The level on which the openings are located fluctuates indoor temperature from comfort conditions (*table:5.2.2 test nos:5.2.2.1, 5.2.2.2, 5.2.2.11, 5.2.2.12*. Openings on the same level), to below comfort (*table:5.2.2 test nos:5.2.2.3-5.2.2.10 and 5.2.2.13-5.2.2.15*. Openings on different level) . It is noted that the bigger the distance between openings the lower the temperature drops. Openings located on the upper floor at 5 meters distance reduce indoor temperature by 1 degree more than when located at 1 meter distance (*compare 5.2.2.14 with 5.2.2.15 and 5.2.2.3 with 5.2.2.5*). Orientation bears no effect on temperature up to this extent of open window area (compare 5.2.2.1, openings facing South, with 5.2.2.2, openings facing North. Also compare 5.2.2.11 with 5.2.2.12).

**(II) Open Window Area - 3.5 m<sup>2</sup> :** As above the effect of this extent of open window area during winter days causes varied effect on indoor temperature, depending on the level and the orientation of the openings. Open windows of this area, located on the same level reduce indoor temperature below comfort between 24.00-09.00 hours (*Table: 5.2.2 test nos:5.2.2.16 and 5.2.2.17*). Openings of the same area, located on different heights reduce indoor temperature by 5.0 degrees and fluctuate it below comfort level during all hours (*test no:5.2.2.18*). This area of open windows, facing north, reduces indoor temperature by 0.2 more than when facing south (*test nos:5.5.2.16 and 5.2.2.17*).

**(III) Open Window Area - 7.5 m<sup>2</sup> :** An open window area of this extent, facing south drops the indoor temperature below comfort between 22.00-10.00 hours (*test no:5.2.2.19*). The same open area, located on the same level, drops the indoor temperature below comfort during all hours when facing north. The average temperature reduction is 5.0 degrees more when open windows face north (*Table: 5.2.2.20*). Splitting the area of 7.5 square meters on two different levels, drops the indoor temperature by 5.0 degrees more than when located on the same level (*compare test nos: 5.2.2.19 and 5.2.2.21*).

**(IV) Open Window Area - 17.50 m<sup>2</sup> :** Increasing the extent of open window area, causes reduction of the indoor temperature below comfort, during all hours, regardless the level of openings or their orientation (*test nos:5.2.2.22-5.2.2.23*). The reduction of indoor temperature is larger if the



openings are positioned on different levels (compare *test nos:5.2.2.22 and 5.2.2.23*) and drops below outdoor between 11.00-14.00 hours. This is the warmest outdoor time of the day. During all other hours the indoor temperature remains higher than outdoor.

**(v) Open Window Area - 35.00 m<sup>2</sup> :** This open window area drops the indoor temperature below outdoor between 10.00-15.00 hours. During all other hours the indoor temperature is higher than the outdoor (*Table: 5.2.2.24*).

**(vi) Open Window Area - All = 40.00 m<sup>2</sup> :** If all window area is left open the indoor temperature drops in the same level and pattern as in previous test. The mass of the structure retains the heat gains of the day, and dissipates it with a time lag. This maintains the indoor temperature above outdoor between 15.00-10.00 hours from 0.5 to 5.0 degrees. The minimum outdoor temperature is 6.5 degrees, whereas the indoor is 8.5 degrees (*Table: 5.2.2.25*).

### 5.2.3.2 Concluding Remarks on winter Infiltration Strategy

The results derived from building simulations, of varied open window area during winter days, indicate fluctuation of indoor temperature in relation to level, orientation and area:

**(i) Level:** The programme used is based on the stack effect for the prediction of temperatures. Therefore the difference of level of the open windows becomes critical for ventilation rates. An area of 1 square meter alone is sufficient to drop the indoor temperature below comfort conditions during all hours when located on different levels (*test and table nos: 5.2.2.3-5.2.2.7*). When on the same level an area of 7.5 square meters is needed (*test no:5.2.2.20*). It is also noted that the bigger the difference of distance between openings the higher the deviation from comfort conditions (*compare test no:5.2.2.3 and 5.2.2.4 also 5.2.2.14 and 5.2.2.15*).

**(ii) Orientation:** An equal area of 7.5 meters square, facing north, drops indoor temperature at lower levels than when facing south (*compare test nos: 5.2.2.19 and 5.2.2.20*). Moreover the larger the open window area the bigger the temperature difference in respect to orientation (*compare 5.2.2.16 and 5.2.2.17. Also 5.2.2.19 and 5.2.2.20*)

**(iii) Area:** The indoor temperature drop increases as the open window area increases. However the temperature reduction is not linearly proportional to the open window area (*compare test nos: 5.2.2.12, 5.2.2.17, 5.2.2.19 and 5.2.2.22*). It is further observed in the tests that the indoor temperature does not drop below outdoor; except the worse scenarios (all windows open *test no:5.2.2.25*) the indoor temperature ranges between 0.2-0.7 degrees lower during the warmest outdoor hours (between 11.00-15.00 hours). All other hours the indoor temperature lies above outdoor by 0.5 to 5.0 degrees.

The above observations are accentuated in real life since the ventilation



prediction model incorporated in the programme is only stack driven. In reality, if a window is left open, the cold outdoor air enters the building and lowers the indoor temperature. It is therefore concluded, from this series of tests, that all openings should be kept closed during winter in order to ensure comfort conditions indoors.

The programme does not incorporate variations of surface characteristics for specific duration of the day, other than the 24 hours. Thus, it is not possible to examine the effect of limited open window area during the warmest hours of the day (14.00-15.00) for ventilation purposes.

#### **5.2.4 CONCLUDING REMARKS ON INFILTRATION/VENTILATION STRATEGY**

##### **General**

The above study focuses on the analysis of occupancy intervention in optimized infiltration and ventilation strategies derived in the previous chapters. In this, characteristics of the windows, are specified in terms of geometry and physical dimensions in infiltration and ventilation profiles, in simulations of the **"Zero Energy House"**. The intention is to describe synthetically how the quality level of the internal environment is affected in response to hypothetical occupant window use patterns. These accommodate possibilities of potential conflicts of the multiple role of windows and destructive interference with the effective performance of the **"Zero Energy House"**.

Tables 5.2.1 and 5.2.2 sum up the attempt to systematise various possible window operations by occupants. It aims to illustrate the correlation between solar heat gains or losses resulting from such operations, for the two seasons, and the thermal performance of the **"Zero Energy House"**. This is done in order to conclude optimum infiltration and ventilation design strategies for maintaining comfort conditions in the building considering the operational aspects of windows.

From the results it is evident that the occupants' interference and misuse of the manually operated windows could be counter-effective and might annul the optimized fenestration design for **"Zero Energy House"** concluded in the previous chapters of the study. The uncertainties associated with the window variable and occupant behaviour can be large in occupied buildings. This occurs, where prevention of heat losses is necessary in winter; also where ventilation is a significant part of the design in achieving in the summer indoor comfort conditions without the need of mechanical energy, as in the case of the **"Zero Energy House"**.

##### **Summer**

Table 5.2.1.0 illustrates the optimized design strategy for summer, with all windows closed during the day and open at night. The outside temperature reaches a maximum of 35.0 degrees Celsius whilst the inside reaches only 26.6 degrees.



### Summer Night Ventilation

The results conclude to the effectiveness of night ventilation which retains the building structure cool, throughout the day.

They also indicate the necessity of having openings on the ground as well as on the upper level of the house, in order to activate high ventilation rates through stack effect. It is found that two open windows, of an area of 1 square meter on different levels reduce operational constraints of windows (*test no:5.2.1.9*). Automatic controls can ensure the two windows to be kept open for the provision of sufficient ventilation in the summer nights, in order to maintain thermal indoor comfort.

### Summer Days

Examining the results of the counter-effective human intervention in the use of windows, on the "all-shut" optimized profile for summer days (*Table 5.2.1.0*), it is noted that this poses no significant conflict on heat gains control. This is provided there is no interference with the night ventilation strategy described above.

Comparing the free thermal behaviour of the building under the optimized summer strategy (*Table 5.2.1.0 "All Fenestration Closed"*), with the less than optimized (*Tables 5.2.2.1-5.2.2.25*), the rise 0.1 to 1.0 degree Celsius of internal temperature indicated for some configurations presents no serious problem. Even when all windows remain open during summer day the internal temperature does not deviate from the comfort zone. Over the complete period of investigation the deviation did not exceed 1.00 degree Celsius, indicating at least for the ventilation variable, the efficient performance of the night ventilation for the summer season. This is confirmed by a test in which all windows are kept closed at night and a window area remains open during the day; the indoor temperature increases at much higher rates than when windows are kept open at night (compare *test nos:5.2.1.11 with 5.2.1.12*).

The results emphasize the significant role of maximum summer night ventilation on the thermal performance of the "Zero Energy House" as proposed above for the "*Summer Night Ventilation*".

### Winter

The results explicitly indicate that the counter-effect of misused windows could be of vital importance for the maintenance of internal thermal comfort level in winter. Table and graph 5.2.2.0 show temperatures of ambient outdoor and indoor air. Table 5.1.0 portrays optimized design for winter, in which all windows are kept closed. It illustrates that while the ambient outdoor air temperature varies from 6.5 to 14.0 degrees Celsius, the swing in the inside temperature remains within the comfort zone, from 18.1 to 19.9 degrees only.

The other tables and graphs numbered from 5.2.2.1 to 5.2.2.25 indicate a drop of indoor temperature ranging from 0.1 to 10.0 degrees Celsius, depending on the level, area and orientation of windows left open during the winter day. If all windows are left open, the internal temperature drops below outdoor, by 0.2



to 0.7 degrees. The largest drop occurs mainly between 10.00 to 15.00 hours (*table 5.2.2.25*). These results point out the reliance of the "Zero Energy House" on an airtight structure, and the necessity of keeping all windows closed. A way of ensuring closed windows in the house is by incorporating in the design an alarm system to warn occupants of windows left open, and/or by providing mechanical ventilation.

### **Final Comments**

The above indicate that the counter-effect of misusing windows in either season might defeat the optimized performance of the "Zero Energy House" to the extent of dropping indoor temperature below outdoor during winter or raising it above outdoor in the summer (*Test nos: 5.2.1.5-5.2.1.8 and 5.2.2.14-5.2.2.25*).

The introduction of automatic controls could eliminate the negative effects of the manually operated windows. These devices may serve well even when residents are away during holidays or weekends. It is possible to generate cooling air flows in the summer nights by the strategic placing of windows with automatic controls (preferably thermostatically operated) and use of stack effect.

In the "Zero Energy House", for the summer season, the open bathroom window on the upper floor and the toilet or kitchen window on the ground, maintain comfort conditions indoors (*test nos:5.2.1.9-5.2.1.11*). In winter an alarm system could be used as warning when windows are left open.



### 5.3 FIELD-STUDY

In the previous chapter the series of combinations of parameters of ventilation and sun control have produced data on the performance of the "Zero Energy House" considering pattern of life when occupied by "standard" Cypriot family. The concluded strategies of the two variables aim in counteracting possible risks of defeating the optimal performance of the "Zero Energy House" due to unexpected occupant behaviour relating to fenestration malfunction (5.1.3 "Concluding Remarks on Shading Strategy" and 5.2.4 "Concluding Remarks on Ventilation/Infiltration Strategy").

Irrespective of how correct and possible the results from the simulations might be, the indoor comfort conditions incurring in all tests in ventilation profiles for summer days necessitated further investigation. As no test or computer simulation can anticipate what will happen in reality this chapter attempts to further investigate the variable of ventilation and demonstrate the technical feasibility of the fenestration design considerations, through a field study similar to that outlined for the "Zero Energy House." (5.3 Field Study Building Description) In this the effect of the ventilation parameter is tested in a series of combinations of open fenestration for the summer. The field study residence was monitored using two identical thermohygrometers located one internally and the other externally. Each weekly profile records the humidity and temperature during the 24 hour span of a day. The results are summarised in table 5.3.0 (*Field-Study for Summer Ventilation*) and the actual recordings are attached in appendix 5.3.

In the field study the following profiles were tested:

1.     **All Windows Closed Between 07.00-20.00 Hours**  
        **All Windows Open Between 20.00-07.00 Hours**
2.     **All Windows Open 24 Hours**
- 3-7.   **Window Area 1.50-3.50 m<sup>2</sup> Open 24 Hours**
8.     **Window Area 2.00 m<sup>2</sup> Open Between 20.00-07.00 Hours**
9.     **Window Area Open at Occupants Will**

From the temperature recordings of these profiles and the comparison with simulation results from corresponding profiles (5.2 "Ventilation/Infiltration") the following are concluded:

#### 5.3.1 All Windows Closed Between 07.00-20.00 Hours All Windows Open Between 20.00-07.00 Hours

In the previous chapter from the series of ventilation simulations, this was



concluded as the optimized ventilation profile (*Table 5.2.1.0*). In the case study the recordings from the controlled tests (*Table 5.3.1.0*) confirm this conclusion. In addition the following are observed:

- (i) The recorded internal temperatures compare well with the indoor temperatures derived from the simulations (5.2.1.0 "Optimized Ventilation Strategy").
- (ii) The external peak temperatures recorded in the field study are by average 4 degrees Celsius higher than those taken in the simulations. The same difference is reflected in the internal temperatures.
- (iii) During the day the profile presented no difficulty in implementing.
- (iv) During the night the wind caused disturbance at times and the temperatures dropped to levels necessitating addition of bed covers.
- (v) The recorded internal temperatures do not reflect the bedroom temperatures as the thermohygrometer was located in the living room which has no direct cross ventilation. All the bedrooms have two to three openings in adjacent and/or on opposite walls.

### 5.3.2 All Windows Open 24 Hours

From this ventilation profile the following are observed:

- (i) The indoor temperature recordings of the field-study (*Table 5.3.2*) are in accordance with the results derived from simulations of the corresponding profile (*Appendix 5.2.1, Table 5.2.2.25*). The difference of the external temperatures is taken into consideration.
- (ii) Indoor temperature was kept at comfort levels at all times.
- (iii) Comparison with ventilation profile 5.3.1, in which the windows are closed between 07.00 to 20.00 hours, indicates that indoor peak temperatures build up at higher levels when windows are kept open 24 hours.
- (iv) Comparison with ventilation profiles, having smaller window area open, shows that the 24 hours all open windows keep the internal peak temperatures for longer time (5 to 6 hours).
- (v) The profile presented difficulties in implementing, both during the day as well as during the night due to discomfort caused by wind.
- (vi) The recordings were taken for three days only due to technical difficulties.

### 5.3.3-7 Window Area 1.50-3.50 m<sup>2</sup> Open 24 Hours

In these series of ventilation tests the following were observed:

- (i) The results from the building simulation ventilation profile, shown in table 5.2.1.10, in which an area of 2.0 sq. meters is left open 24 hours, compare well with the corresponding recordings from the case study shown on graph 5.3.5. However the internal temperature recordings of



the case study (of the same external temperature as the simulation for Thursday, Friday, Saturday and Sunday) are lower by average 1 degree Celsius.

- (ii) Reduction of the open 24 hours window area lowers the internal temperatures during the hottest hours of the day (*compare 5.3.4 with 5.3.5, 5.3.3 with 5.3.6 and 5.3.3 with 5.3.7*).
- (iii) Orientation of open windows on opposite sides results to lower internal temperatures than on adjacent walls (compare temperature recordings on *tables 5.3.6 with 5.3.7*).
- (iv) The closer the open window area to the thermohygrometer the lower the recorded temperatures are. This is indicated by comparing recordings on graph 5.3.3 and 5.3.4. Both tests have the same open window area and are under the same conditions. The only differentiating factor is the distance; in the former an open window area of 1 square meter is at a distance of 5 meters further than the latter from the thermohygrometer. On graph 5.3.3 the external peak temperature (during Thursday) is 38.6 degrees Celsius, while the internal lies between 30.0 to 31.0 for 6 hours (14.00 to 20.00 hours). On graph 5.3.4 the external peak temperature (during Thursday) is 38.8 degrees Celsius, and internally it lies between 28.0 to 30.0 for 6 hours (14.00-20.00 hours).

### **5.3.8 Window Area 2.00 m2 Open Between 20.00-07.00 Hours**

In this ventilation profile two windows are left open at night only and the following are noted:

- (i) The temperature recordings are in accordance with the simulation results shown on table and graph 5.2.1.9 of the corresponding ventilation test.
- (ii) The indoor temperature is kept at lower levels and does not present the degree of fluctuation as the recordings from the ventilation profile of the same conditions but which has the specified window area opened 24 hours (*compare graph 5.3.8 with graph 5.3.5*).

### **5.3.9 Window Area Open at Occupants Will**

In these tests the opening of windows was regulated by the inhabitants and the mode and duration of the opened window area were recorded. The following are noted:

- (i) Throughout the day an area of 0.50 square meters was left open for ventilation (kitchen window left partly open).
- (ii) At 19.00 hours at least one window in each room opened for 1 to 3 hours.
- (iii) During the night at least two in the residence windows were kept open for cross ventilation.
- (iv) The indoor temperature was kept at comfort levels at all times.
- (v) Comparison with the optimized ventilation profile shows that the



occupants regulation of ventilation results to more uniform internal temperatures (*compare graph 5.3.9 with graph 5.3.1*).

### 5.3.10 General Comments

From the field study the following are concluded:

- (a) **Correlation of Simulations and Recordings:** The temperature recordings from the case study confirm the validity of the results derived from the simulations of the "Zero Energy House".
- (b) **Ventilation and Occupants:** (i) The large diurnal temperature fluctuations and the variable wind pattern often necessitate ventilation regulation by the occupants *15.3.1 (iv) and 5.3.2 (v)*.  
(ii) Regulation of ventilation by occupants maintains indoor comfort conditions *15.3.9 (iv), (v)*.
- (c) **Ventilation Hours:** (i) The longer the span of open fenestration during the day the higher the internal temperatures rise *15.3.2 (iii)*.  
(ii) The longer the span of open fenestration during the night the lower the internal temperatures drop *15.3.8 (ii)*.
- (d) **Fenestration Area:** (i) The larger the area of open fenestration during the day, the higher the levels of internal temperatures rise *15.3.2(iv), 5.3.7 (ii)*.  
(ii) The larger the area of open fenestration during the night the lower the levels of internal temperatures are maintained *15.3.8 and 5.3.9) 1*.
- (e) **Fenestration Proximity:** The closer the open fenestration area to the indoor space the more immediate and predominant the cooling effect is on that space *15.3.3-5.3.7 (iv)*.
- (f) **Fenestration Orientation:** Open fenestration at varying directions, causing cross ventilation, result in cooler indoor temperature levels *15.3.3-5.3.7 (iii)*.



Table 5.3: FIELD STUDY BUILDING DESCRIPTION

(a) Location	Nicosia		
(b) Type	Single Family, Detached, Two Storey		
(c) Size	Area = 200m <sup>2</sup> , Height = 6.0m		
(d) Shape	Two Storey, Rectangular		
(e) Layout	Bedrooms Upstairs-Other rooms Downstairs		
(f) Components	Roof	:Concrete slab 200mm+Screed+Insulation	
	Walls	:Brickwalls - Plastered - Painted	
		:External = 200mm	
		:Internal = 100mm	
	Floor	:Concrete slab 200mm + Tiles	
	Windows	:Aluminium Frame - Single Glazed	
	Doors	:External = Aluminium	
		:Internal = Flush Timber	
(g) Shading	None		
(h) Air-Conditioning	None in Operation		

Photo 5.3: South Elevation of Field – Case House

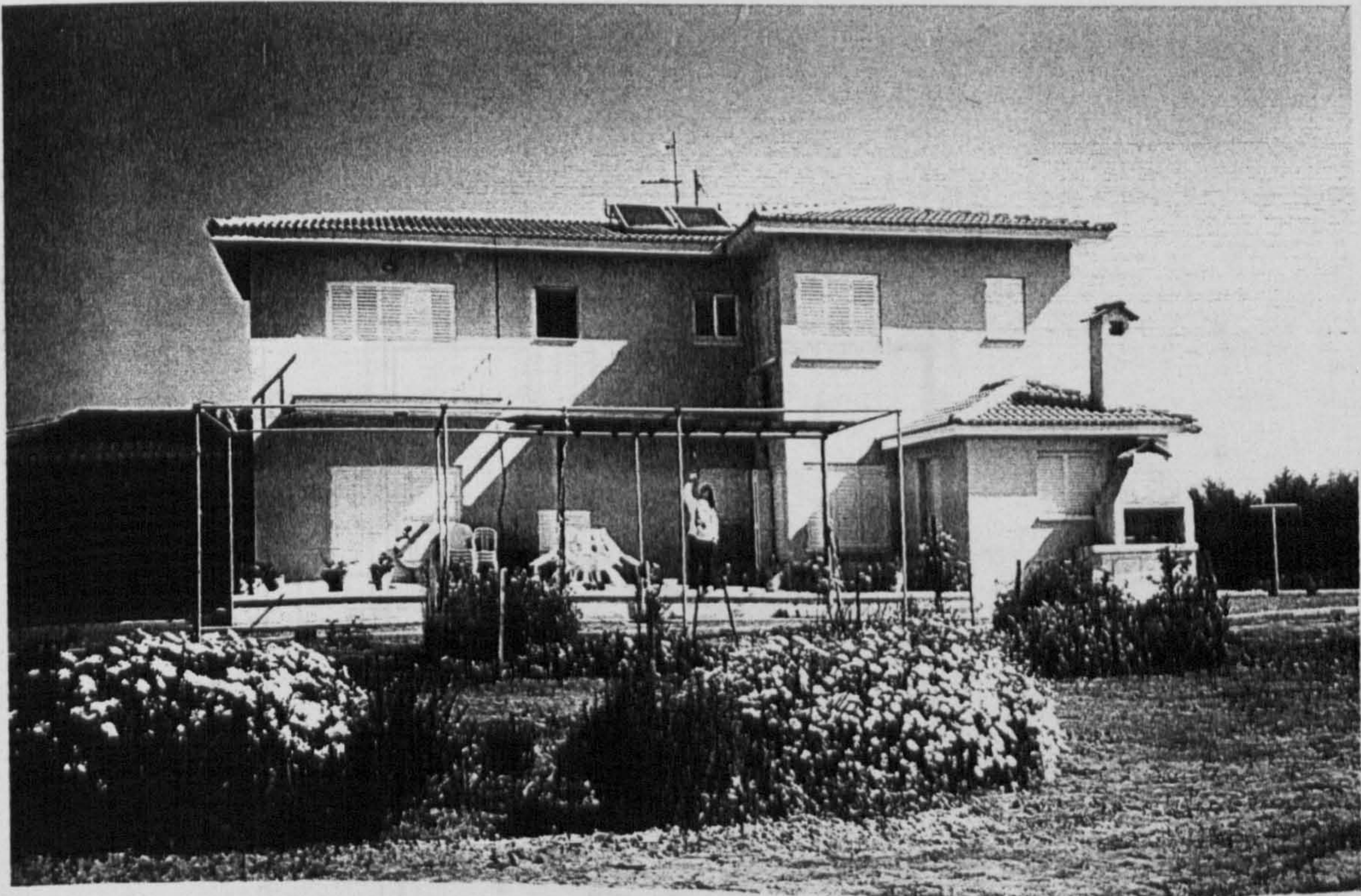








Table 5.3.0: FIELD STUDY FOR SUMMER VENTILATION

TEST		OPEN WINDOW'S			TEMPERATURE (°C)	
NO	AREA (m²)	ASPECT	HOURS	REMARKS	EXTERNAL	INTERNAL
5.3.1	17.0 5.0 1.5	WEST SOUTH EAST	20.00-07.00 ▪ ▪	All open-Night All closed-Day	24.0-38.8	26.0-29.0
5.3.2	17.0 5.0 1.5	WEST SOUTH WEST	00.00-24.00 ▪ ▪	All open-24 hours	22.0-40.5	24.0-30.0
5.3.3	3.0 0.5	WEST EAST	00.00-24.00 ▪	Open - in 4 rooms	24.0-39.1	26.0-32.0
5.3.4	3.0 0.5	WEST EAST	00.00-24.00 ▪	Open - in 4 rooms	23.0-38.8	26.0-31.0
5.3.5	2.0 0.5	WEST EAST	00.00-24.00 ▪	Open - In 3 rooms	23.0-37.0	26.0-30.0
5.3.6	2.0	WEST	00.00-24.00	Open - In 2 rooms	25.0-40.5	27.0-32.00
5.3.7	1.0 0.5	WEST EAST	00.00-24.00 ▪	Open - In 2 rooms	24.5-39.1	25.5-30.5
5.3.8	1.5 0.5	WEST EAST	20.00-07.00 ▪	Open - in 2 rooms	21.0-42.0	24.0-30.0
5.3.9	0.5 1.0 2.0 1.0	WEST WEST SOUTH EAST	00.00-24.00 20.00-07.00 20.00-22.00 20.00-22.00	Occupants' choice	23.0-38.7	26.0-29.0

Notes:

- (a) Ventilation profiles from 5.3.1 to 5.3.8 (inclusive) were controlled.
- (b) Ventilation profile 5.3.9 is regulated by the inhabitants.
- (c) Peak temperatures are doubled-checked with the Cyprus Meteorological services.



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## **CHAPTER 6**

## **FINAL CONCLUSIONS**



## **6.0 FINAL CONCLUSIONS**

### **6.1 INTEGRATED DESIGN**

The study through analysis and evaluation of alternative design options and hypothetical data, has identified and quantified the principal factors that determine practical efficiency in the "Zero Energy House" for Cyprus. The resultant "Zero House" does not require unfamiliar construction techniques or untried technology and no major changes in the inhabitants' life style are expected. It is suitable for normal urban and suburban sites and it employs different sets of options. It is also concluded from the study, that thermal comfort can be achieved by many different combinations of optimized and effective variables in the "Zero Energy House" such as:

**Compact Shape**  
**Internal Mass**  
**South Windows and Shading Devices**  
**Controlled Infiltration**  
**Summer Night Ventilation**  
**External Insulation**

A change of one can frequently be compensated for by changes in the others. This presents no difficulty in achieving, as it is already concluded (4.4 Summary and Conclusions), if the user's constraints are all cast aside. However, it is necessary to consider both, the practical aspects of the various design options and the effect of the users' intervention.

### **6.2 PRACTICAL DESIGN ASPECTS**

In the following conclusive remarks alternative solutions are given, commending on the practical implications of the design recommendations.

#### **6.2.1 SITING THE HOUSE**

The optimization studies for the "Zero Energy House" have been carried out under ideal conditions assuming a clear sky profile in all the tests. However, when siting the building the following aspects must be considered in order to use effectively adjacent structures and the nature of the land, avoiding their negative effects on the thermal performance of the house:

- (a) Solar Access
- (b) Daylight Access
- (c) Summer Shading
- (d) Reflected Radiation

- (a) Solar Access

In determining the siting of the building solar access must be ensured between



09.00am to 15.00pm in December 21, when the sun is at its lowest path in the sky. The height of neighbouring building, the vegetation and the land masses determine the spacing distance of the building in order to ensure winter sun.

**(b) Daylight Access**

Adequate daylight access, avoiding window side effects in the hot summers of Cyprus is of particular importance since the clear skies and the bright sun require the use of light while excluding the solar heat from the buildings and open space. The light from reflecting surfaces such as the ground or adjacent facades which are usually light colour in Cyprus, reflect the light away from the building and are potential source of glare. To avoid this, the light should be filtered at the window plane. The proposed shading devices (5.1 "Shading") such as wood screens or shutters are ideal for this purpose.

In winter under overcast sky conditions, the light levels are usually lower therefore exterior obstructions of the sky dome are a disadvantage. Also if the cloud cover is very thin, the overcast sky can be very bright and a potential source of glare. The distance and height of adjacent facades, determine the quality and the amounts of light available.

**(c) Summer Shading**

If the site offers several building positions, the choice should be determined on the basis of utilizing existing structures and land masses for the reduction of solar gains from the low afternoon summer sun, by siting the building to the east of such features.

**(d) Reflected Radiation**

The amount of solar radiation received by the ground surface, during summer months in Cyprus is very high (twice that received by either East or West walls) due to the almost vertical incidence of sun rays. This causes large radiation reflected from the ground into windows and external walls and could increase the indoor temperature. It is therefore necessary to shade adjacent ground surfaces around the house and use exterior surface materials of low reflectivity where shading is not possible, in order to minimize solar heat gains. Planted grass or irregular surface of shrubbery intercepts the sun giving lower reflectivity than paved areas and bare ground. The paved surfaces store up and retain more heat for longer duration than unpaved or grass surfaces. The air temperature near the surfaces increases. They also radiate and reflect larger amounts of it in the building.

## **6.2.2 SHAPE AND ORIENTATION**

It is obvious from the study that the development of the building variables in various shapes, into a dynamic and effective pattern of design choices and constraints, necessitates thermal studies for each single building with its own geometry configuration and particularities. Pertaining to the tests on shape (4.2.1 "Shape"), it is found that simple compact shapes are more energy efficient than complex ones. However, it was noted, that variation or introduction of



other parameters on more complex shapes might also render them equally or more energy efficient than simple ones.

On a practical level it is concluded that the designer aiming at Zero Energy could employ any of the four tested shapes (rectangular, L-Shape, Π-Shape or Square Drawings 1-5 p.174-178). Since they all resume to Zero Energy with the introduction of effective parameters (4.2.1 "Shape"). However, in determining the choice of the shape the following must be considered:

- (a) Compact shapes approximating to a square shape are most energy efficient.
- (b) If complex shapes are chosen, insulation on the envelope and major south glazing are imperative.
- (c) In long thin buildings with large areas of south glazing, internal mass facing south must be added on walls.
- (d) The length axis of the building to be oriented East-West with more surface area exposed to the south. This aspecting is ideal for Cyprus as it maximizes solar gain during winter and minimizes the during the summer.

### **6.2.3. BUILDING ELEMENTS**

In designing the building elements the designer must ensure:

- (a) External insulation to prevent heating in the summer and heat losses in the Winter (4.2.4 "Insulation").
- (b) Internal thermal mass to act as heat and cold storage (4.2.2 "Mass").
- (c) Heat reflective materials for surfaces exposed to the summer sun.
- (d) Absorbing materials for surfaces exposed to the winter sun.

#### **A. Walls**

##### **(a) External Walls**

In addition to the thermal insulation and thermal mass the external wall construction is to provide structural strength, weather and impact protection. Considering these requirement, and from the several tests carried on the variables of mass and insulation, in varied wall design, the following construction typesave recommended.

- (i) 250mm cavity brickwall with sandwiched, insulation (test:S8).
- (ii) 250mm cavity wall, 100mm brickwall externally, 100mm concrete wall internally with sandwiched insulation (test: S9).
- (iii) 350mm cavity brickwall, 100mm skin externally, 200mm internally with sandwiched insulation (test: S19).
- (iv) 200mm solid brickwall with external insulation (test:S6).

The bricks are the locally manufactured common bricks whereas rigid extruded polystyrene was used for the insulation in the simulations which is the most commonly used type in Cyprus. Since polystyrene cannot last long in hot



climates, fibreglass which is also available in the market could be used. These types of wall construction, provide useful thermal mass, especially when insulation is placed on the outer surface, heat gain is prevented being stored in the outside skin during the summer days. The cavity wall construction types in which the insulation is contained within the skin cavity are fairly simple to build, they are extensively used in Cyprus and they do not involve unusual expertise. The external skin of the wall is impermeable and provides weather and impact protection. The solid brickwall with insulation on its external surface is a solution which has up to now been chosen to a fairly limited extent and is more difficult to construct and waterproof. Essentially there are three basic types of this system:

- (i) Lightweight renders
- (ii) Rigid insulation panels
- (iii) Flexible insulation mats

The lightweight renders are thermally less efficient than the other techniques. The resistance of proprietary systems to impact damage varies considerably and in some cases a strong decorative finish is needed. This type of construction poses no difficulty in Cyprus as the method and the substrate is prepared as the traditional render. The other two types, of external insulation could be inserted between studs fixed on the wall, covered by metal mesh attached to the wall by pegs passing through the insulation. The mesh is cement-rendered and painted to complete the external surface. Nowadays external insulation products have been developed which retain a rendered surface as a facade finish. Heat reflective materials such as white paint must be used on surfaces orientated to summer sun (east and west walls) and absorbing materials on the south facing walls.

#### **(b) Internal Walls**

These are recommended to be of increased thickness. Solid brickwall 200mm thickness or a 100mm sold concrete wall could replace the current practice of 100mm brickwall. Both provide useful thermal mass. The internal wall surfaces should be light in colour (matt white) to aid the distribution of energy to all surfaces in the rooms and in balancing the daylight within the space.

### **B. Floors**

The current practice of reinforced concrete floor slabs with screed and marble, or mosaic tiles are ideal for the provision of useful thermal mass. The studies show that floor insulation is not necessary. The massive floor must be of dark colour. If the floor is of low-mass or covered with carpet, light colour is recommended to scatter the radiation to other locations where it can be better stored.

### **C. Roofs**

Concrete flat slab roofs with screed to fall, waterproof membrane and insulation



on top provide, useful internal thermal mass, and external insulation to intercept summer solar radiation. A protective layer of durable material such as white chippings or white paving slabs will also act as reflecting materials, necessary for the reflection of the almost vertical summer sun rays. If an inclined or pitched tiled roof is used, the concrete slab construction as in flat roofs, should be preferred to the timber structure to provide sufficient mass. The tiles should be the light pink colour to reflect the sun. Both types of roof were tested in the study (tests: S15, S18). The tiled roof appears to vander more energy savings. It is also in accordance with the traditional local style (Drawings 1-4 p. 174-178)

#### **D. Windows**

##### **(a) Orientation**

- (i) South aspecting glazing is recommended (70% of it is applied in the tests).
- (ii) Avoiding East and West windows to minimize overheating in the Summer.
- (iii) Limiting North fenestration for the provision of daylight and cross ventilation.

##### **(b) Glazing**

Double glazing limits the heat losses in Winter and incurs large energy savings. The cost effectiveness of double glazing depends upon all the other parameters of fenestration. However, from the study is found and concluded that double glazing could be recommended for north facing windows and in cases where sound insulation is necessary.

##### **(c) Shading and Ventilation**

These two window aspects are dealt with extensively under the study of occupants intervention found below.

### **6.3 THE OCCUPANTS**

A house is not merely a container in which people act like robots and are placed to receive its thermal effects. There is a dynamic dialogue between building controls and building use. Furthermore, for the Cyprus climate, it is necessary that some of the employed passive systems for the optimization must be activated by the users in order to be effective.

It was found from the study that the variable of fenestration (Ref:4.1.3 "Fenestration") houses those user interactive parameters which could be critical for the optimal performance of the "Zero Energy House". These parameters are:

#### **Fenestration Shading and Ventilation**

The relative thermal effect of these parameters in many different combinations in building simulations was studied (5.1 "Shading", 5.2 "Ventilation"). Observations from the results converge to the conclusion that the counter-effect of window misuse, in either season, might defeat the optimal performance of the "Zero



**Energy House"** to the extend of dropping indoor temperature below outdoor in the winter or indeed raising it above outdoor in the summer (5.1 **"Shading"** Test nos: 5.1.4 and **"Ventilation"** Test nos: 5.2.1.5-5.2.1.8 and 5.2.2.14-5.2.2.25).

The results show the significance of well aware, well informed, cautious end-users. However the study does not rely on the awareness of the occupants. It proposes design strategies and specific automatic controls which could reduce the operational constraints currently imposed upon buildings ( 5.1.3 **"Concluding Remarks on Shading Strategy"** and 5.2.4 **"Concluding Remarks on Ventilation/Infiltration Strategy"**).

## **Shading**

For Shading it was concluded that optimized design of fenestration overhangs and side-fins, without shutters could best provide sufficient Summer sun control in order to maintain thermal indoor comfort. The results do not dispute the effectiveness of the manually operated window shutters, especially in cases in which the design concern in buildings extends beyond the thermal and physical determinate and the decision to use shutters is dominated by considerations other than energy and thermal comfort. The application of shutters is often circumscribed by a number of design considerations environmental as well as architectural, economic and behavioural. The function of solar control might then be carried as a secondary function and shutters might be installed primarily for privacy, security, night insulation, or as a traditional semantic feature. The role of the shutters as such might then prevent the occupants from availing themselves of the potential of free solar gains to the extend illustrated by the results (*Table 5.1.4*).

Although life styles and social factors, other than those established for a typical household, are outside the scope of the study of the **"Zero Energy House"** and the proposals are confined only within the framework of thermal considerations, three possible shading scenarios are projected which might be accompanied by adverse side-effects as follows:

### **a. Optimized Design of Overhangs/Side fins - No Shutters**

In this shading profile, window glare might be a problem; nevertheless this could be counteracted in different ways such as:

- (i) Introduction of net curtains
- (ii) Grass planting in adjacent ground surfaces.
- (iii) Introduction of pergolas with deciduous plants, a traditional well established practice in Cyprus.

### **b. Shutters on All Fenestration**

This is traditional shading approach and although the simulation results show that misuse of the shutters in winter, could be critical for the optimal performance of the **"Zero Energy House"**, the common practice in Cyprus and the conclusions of the case study reinforce the belief that the intuitive response of the Mediterranean inhabitants is powerful



enough to initiate shutters' shading operation for the maintenance of indoor comfort.

**c. Shutters and Automatic Controls**

Simple automatic sensor devices on shutters could be set to open adjustable shutters struck by sun rays in winter allowing indoors the benefit of solar gains. Incorporating automatic controls, when fenestration shutters are part of the window design, could solve not only possible negative effects associated with manual operational constraints but they also serve well modern life styles of the mostly working couples in Cyprus and absences during holidays and weekends.

## **Ventilation**

Maximum summer night ventilation is derived as the most appropriate cooling ventilation strategy. This could be ensured by embodying in the windows, opening automatic devices which could be activated at specific hours (20.00-07.00). A simple alarm system incorporated in fenestration could also ensure closed windows in winter.

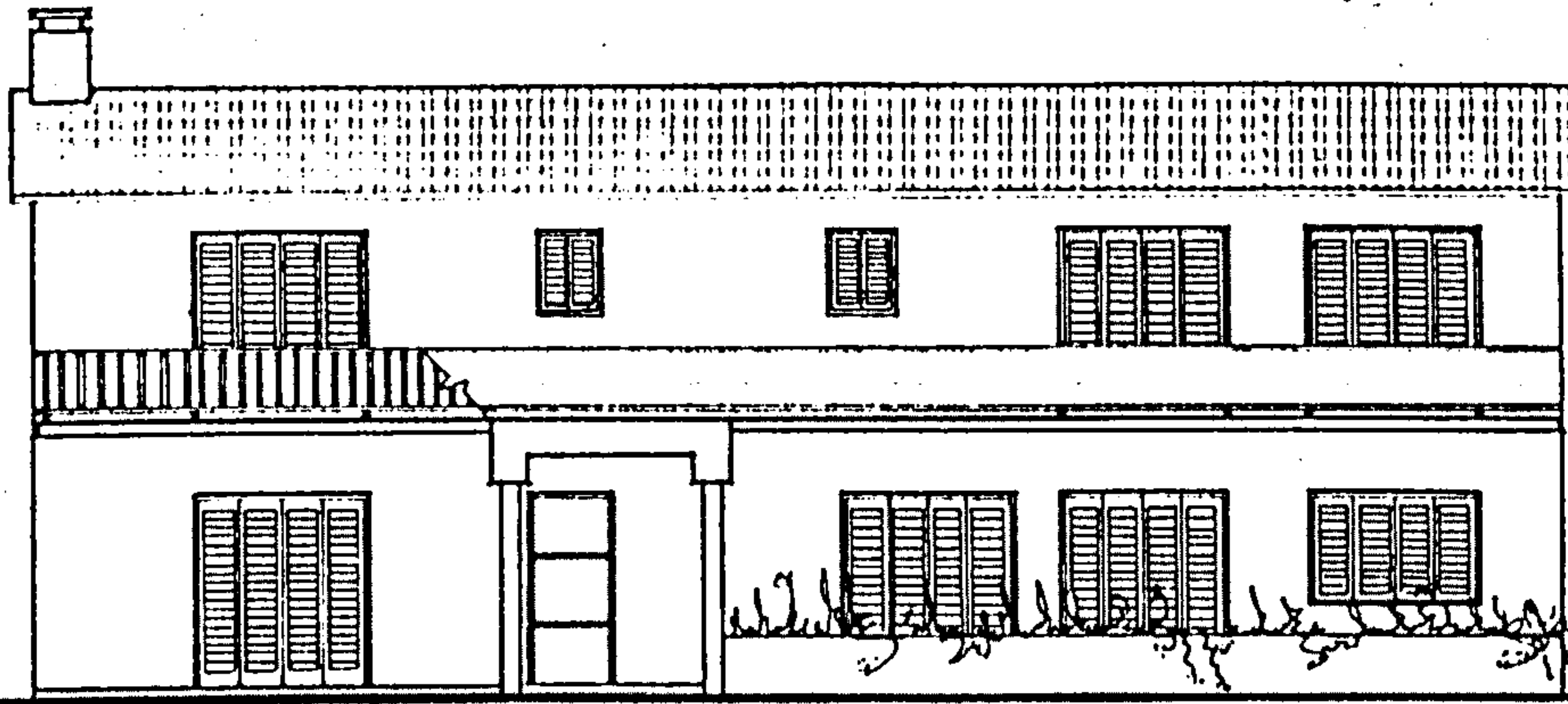
Even so, if automatic devices are not part of the solution and the control of the fenestration is left upon the occupants, it is concluded from the study that this poses no problem during the day in the summer (5.2.4"Concluding Remarks on Ventilation/Infiltration"). During the night due to low external temperatures opening windows has immediate effect in cooling the indoors space (5.3 "Case Study").

Furthermore as it is demonstrated in the ventilation tests the inherent intuitive approach of Mediterranean people in appropriately activating passive design strategies seems to work well in securing optimal performance of "Zero Energy Houses".

## **6.3 FINAL COMMENTS**

It is found from the study that the designer has several design options which offer him a considerable latitude in selecting design combinations for zero energy load. It is also concluded that the adoption of strategies to achieve comfort conditions in houses by the use of passive, manually or automatically operated techniques on the one hand and the willingness and ability of building users to use corrective intervention on the other hand are very powerful tools. The suitable choice of techniques for the inhabitants is also imperative. These should enable sufficient degree of interaction in terms of flexibility between climate on the one hand and the building and its users on the other hand. Therein lies the potential for the successful creation of comfort conditions without the use of mechanical energy demand.

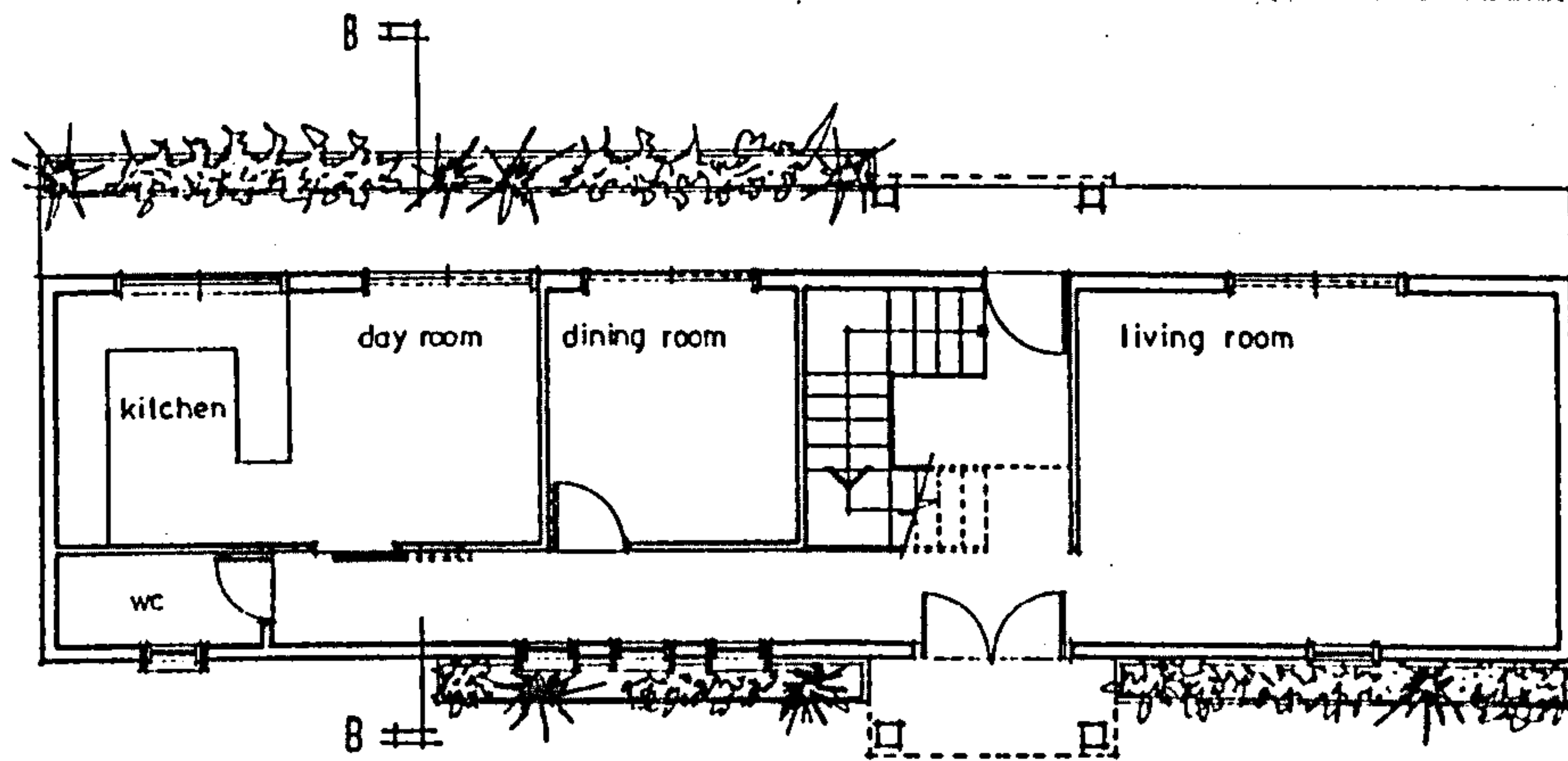




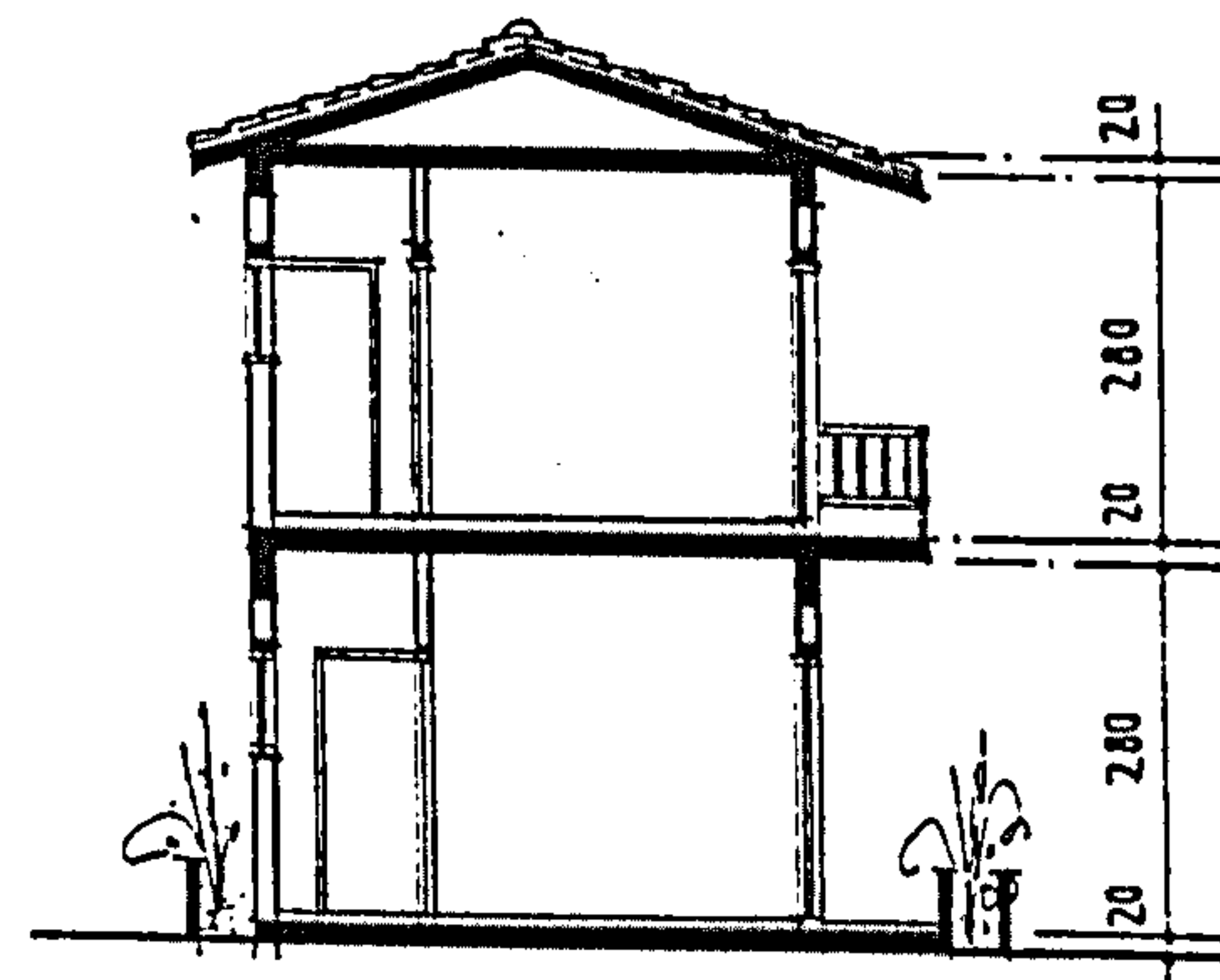
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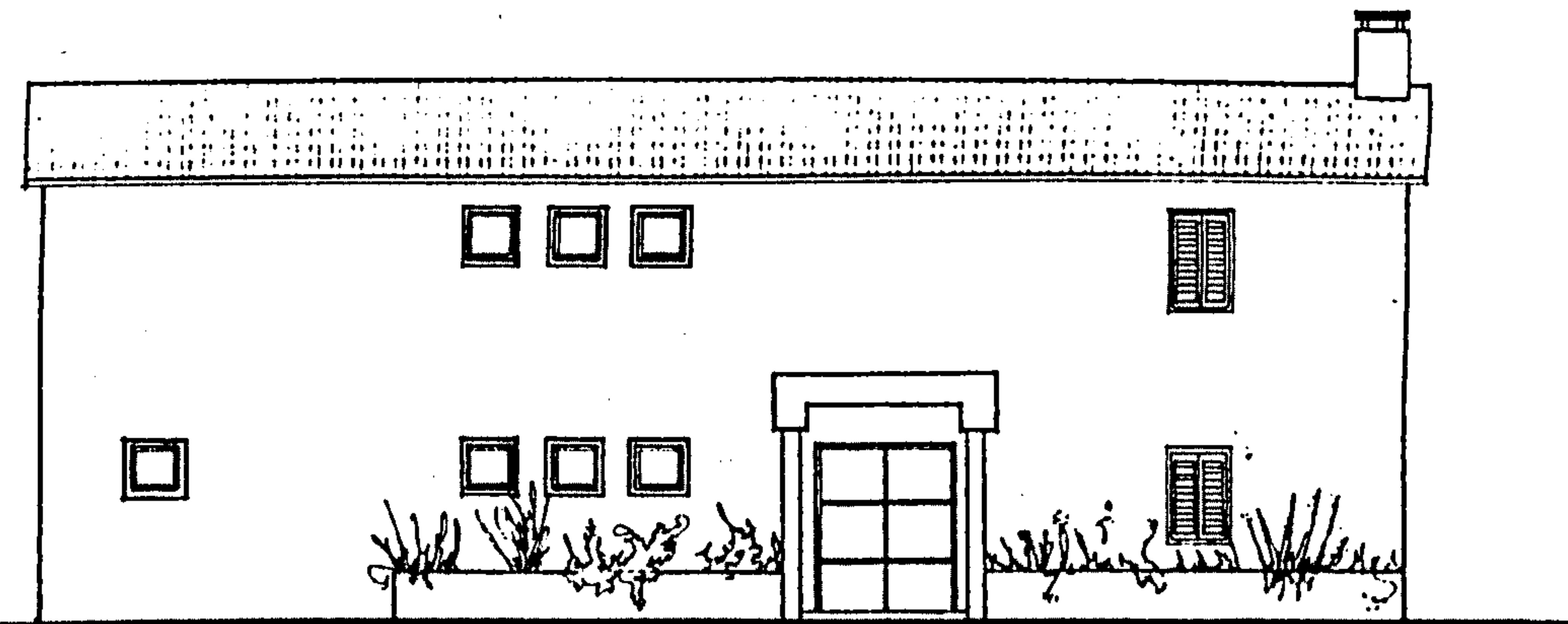
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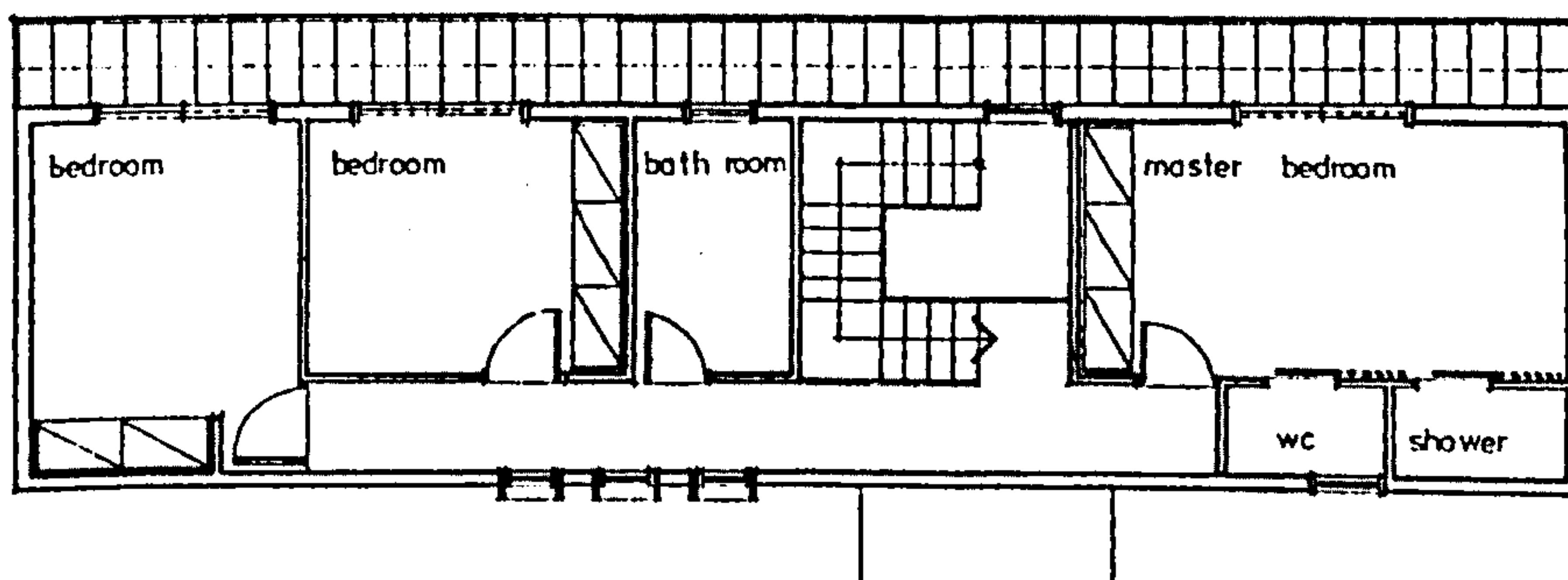
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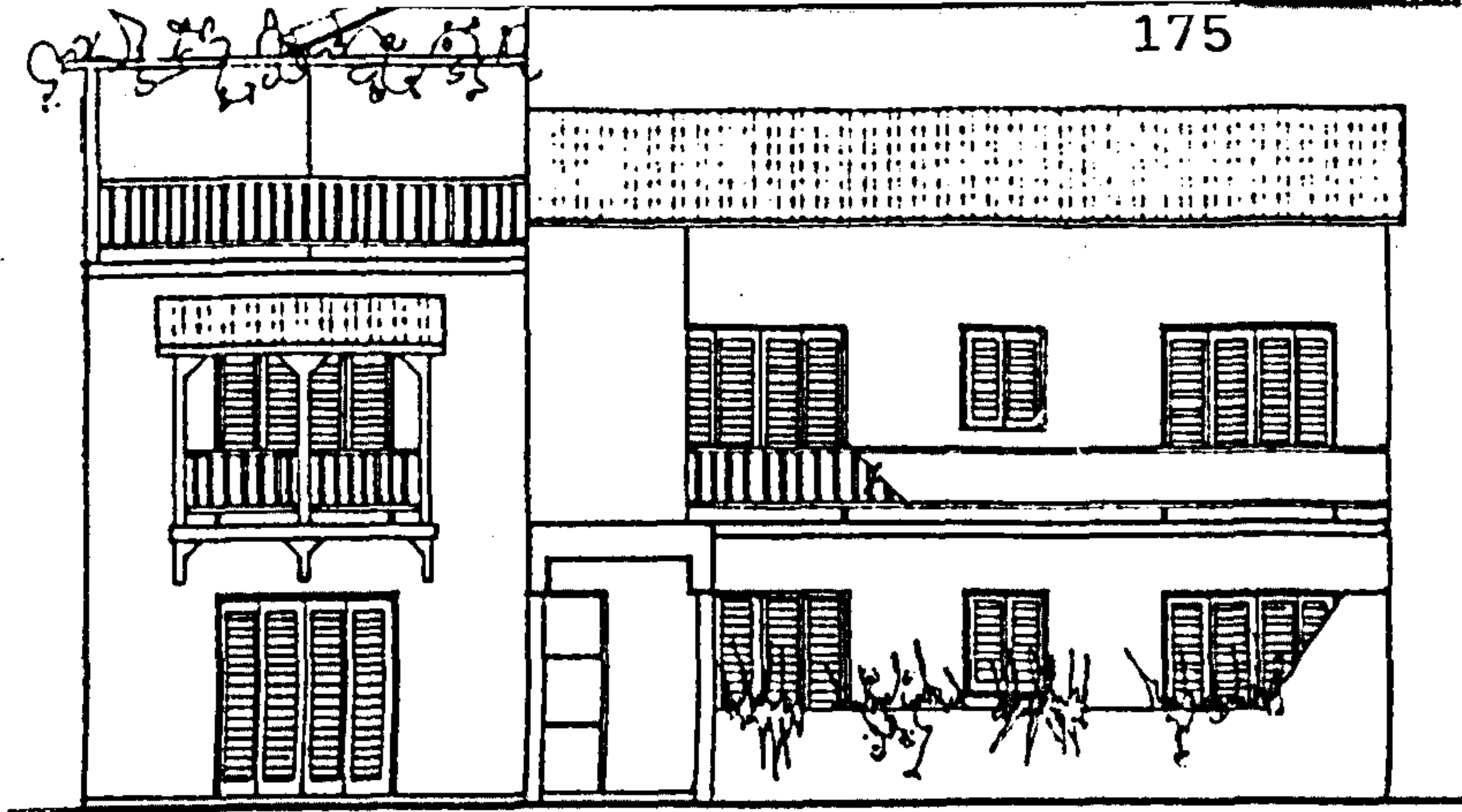


FRONT ELEVATION



FIRST FLOOR





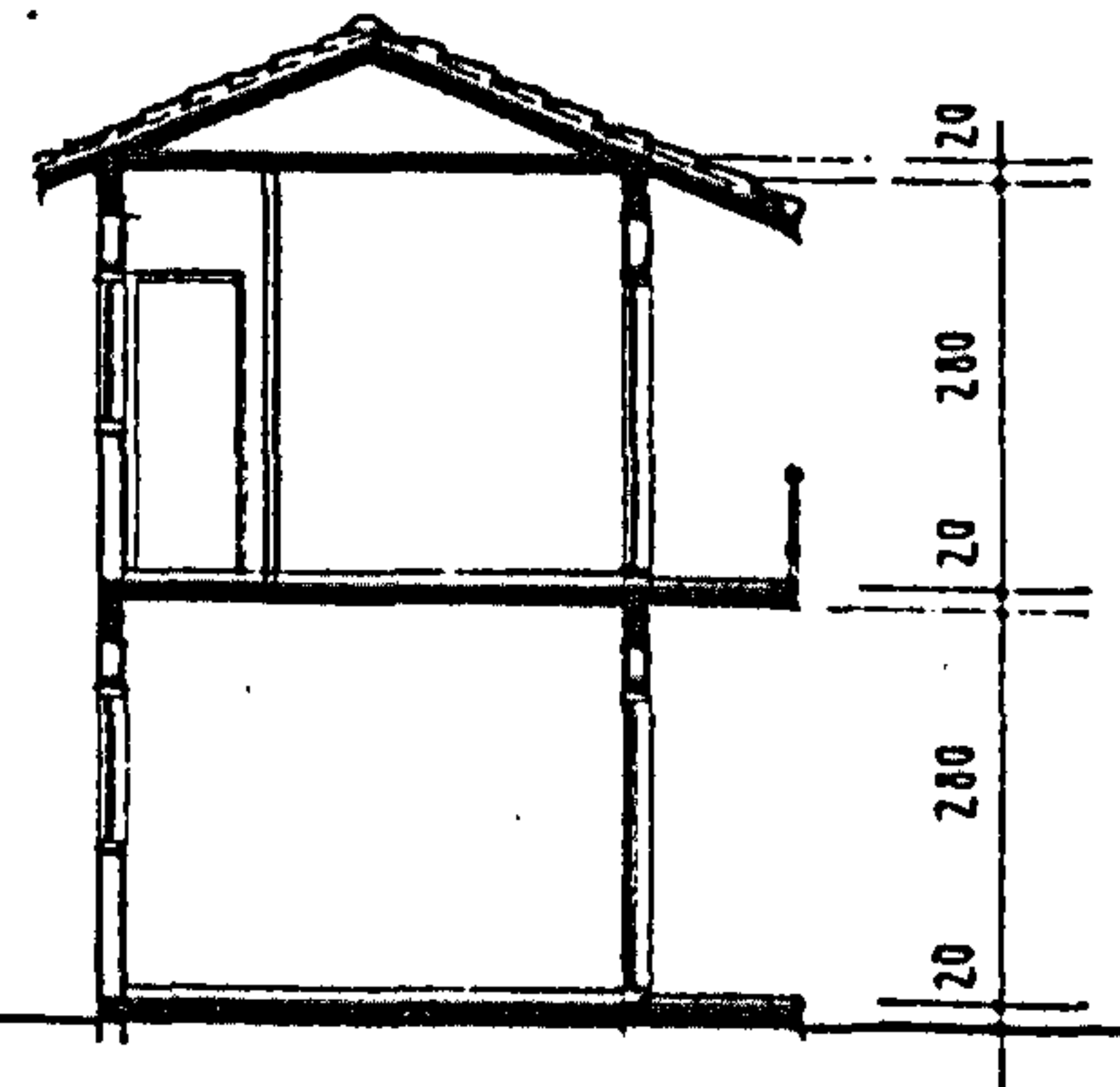
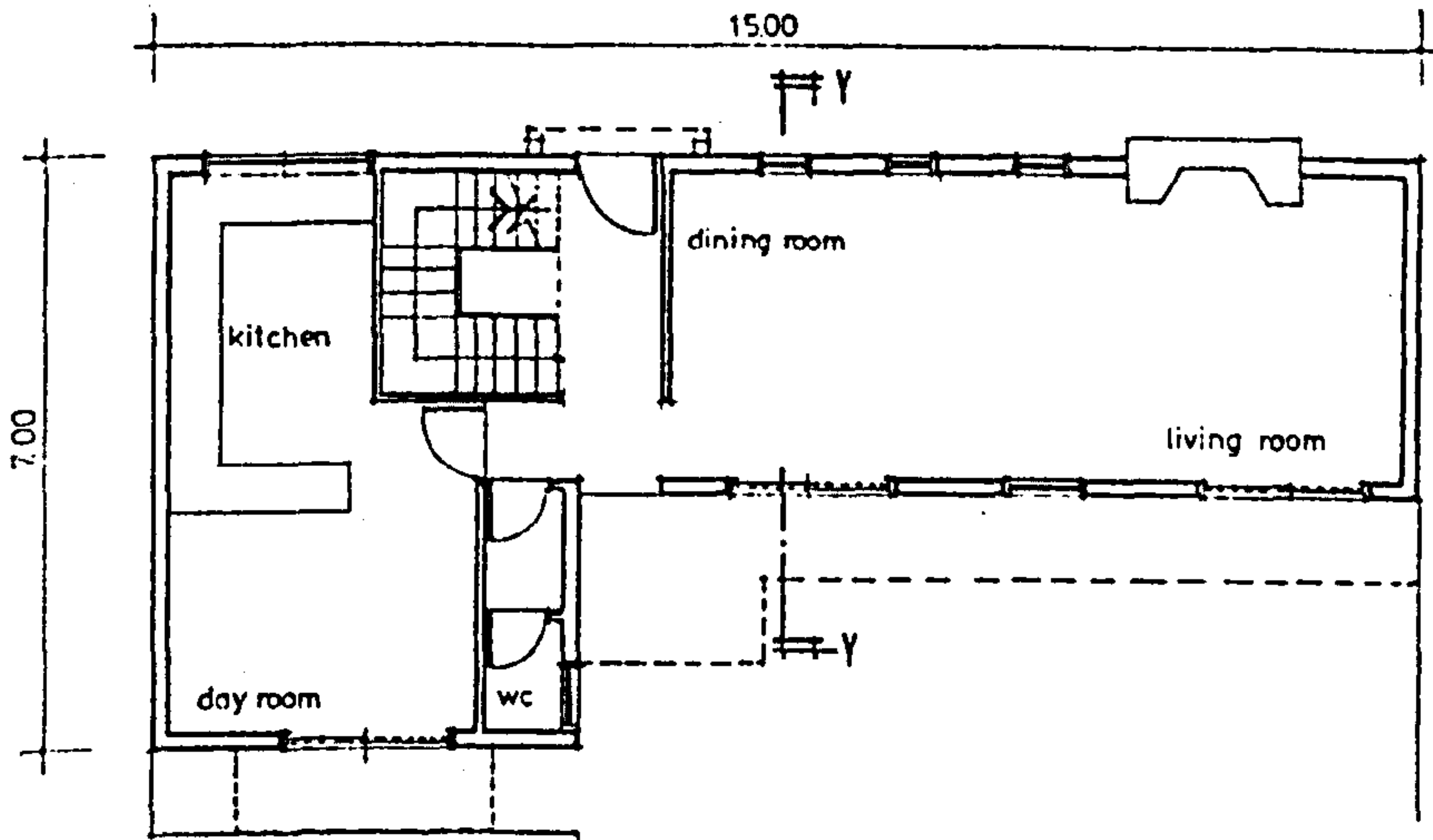
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L - SHAPE HOUSE

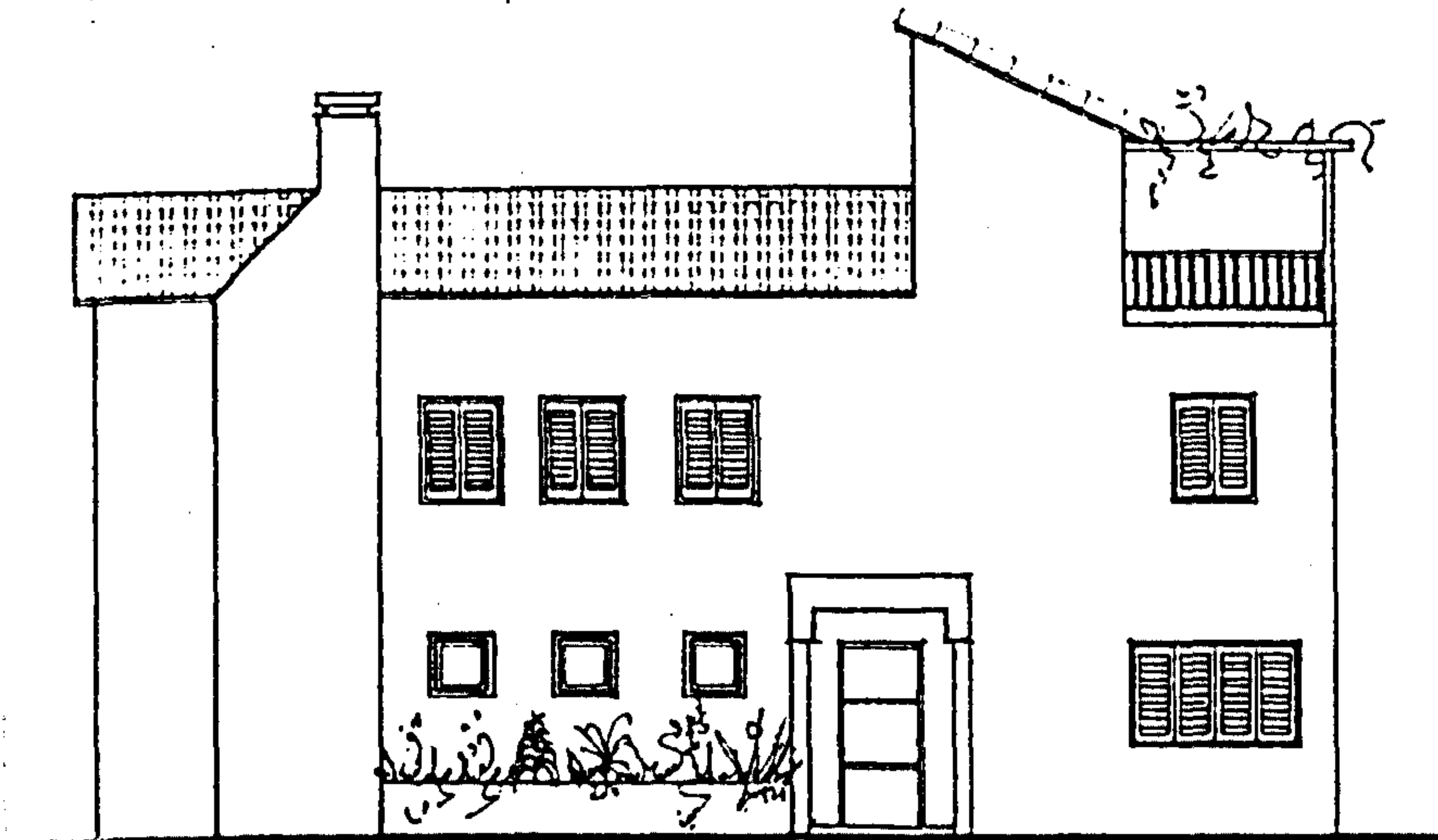
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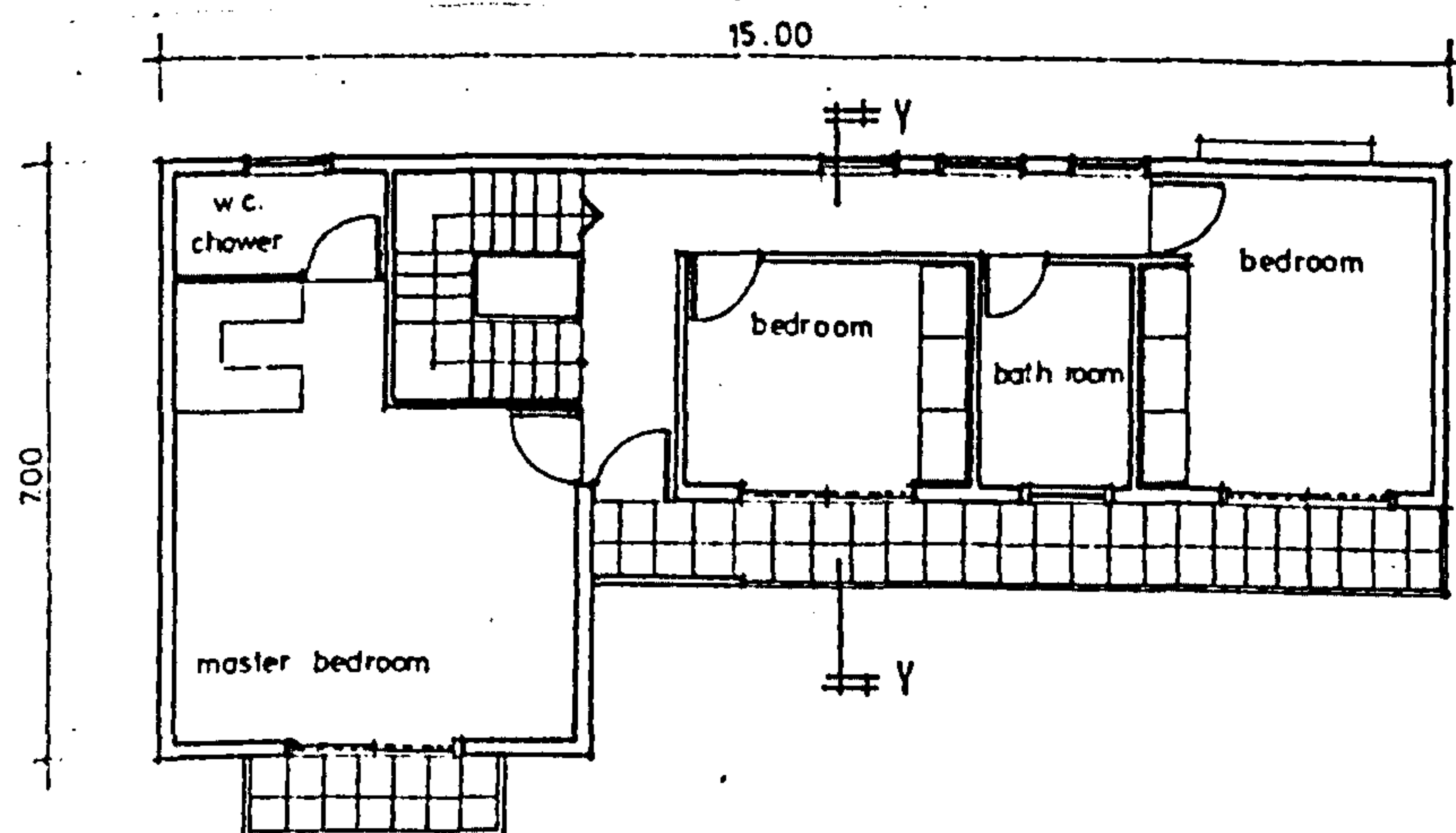
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SECTION Y-Y



REAR ELEVATION



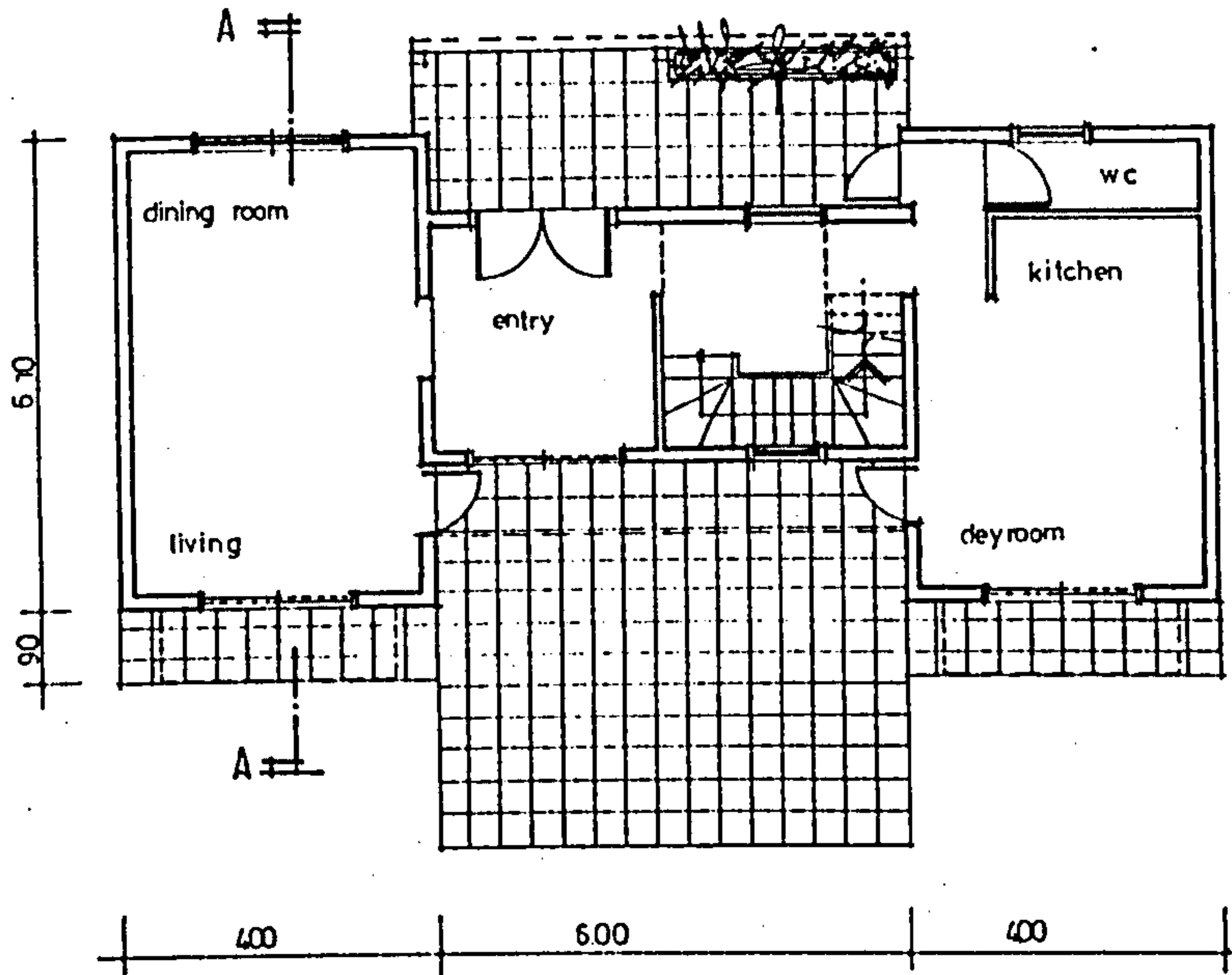
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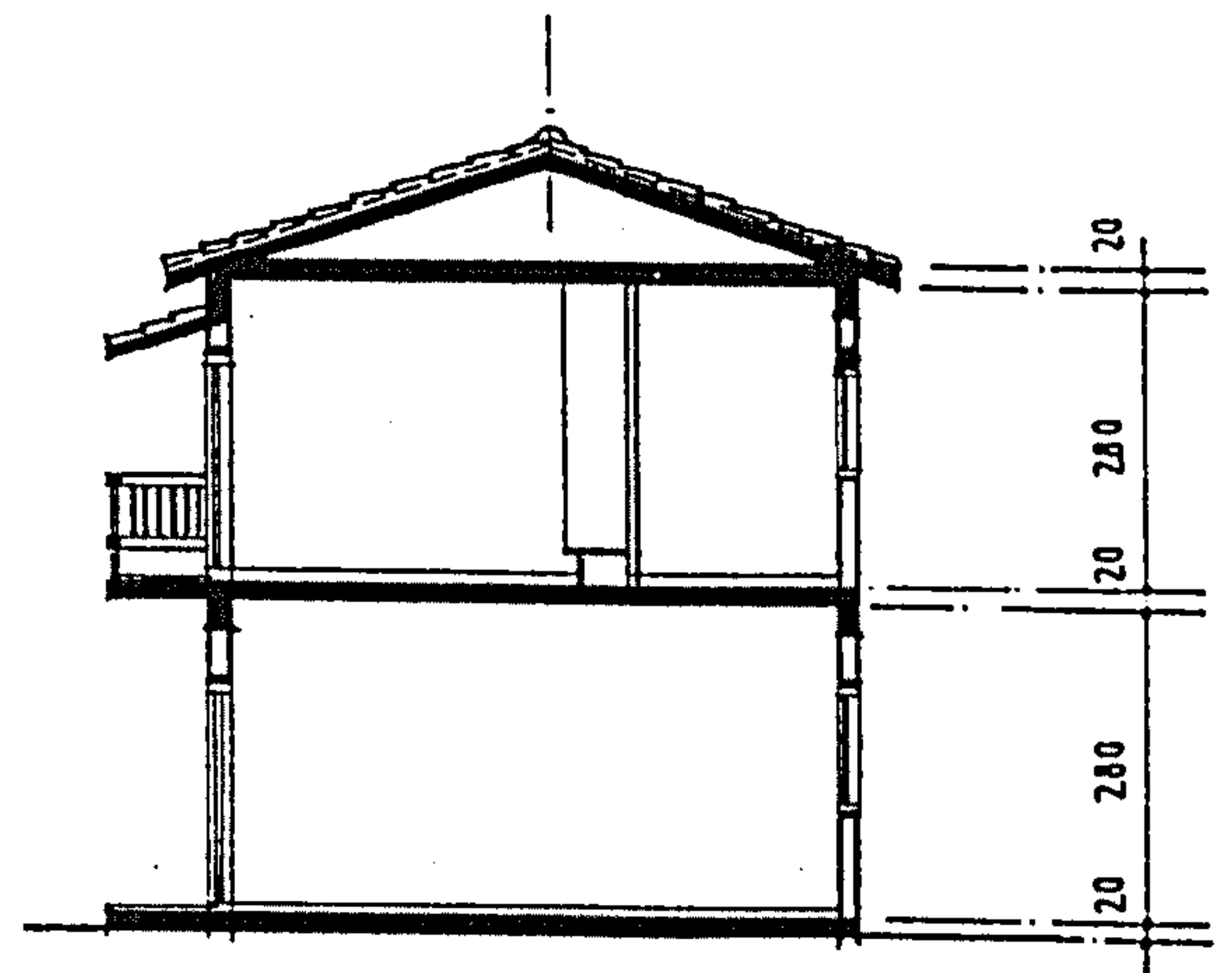


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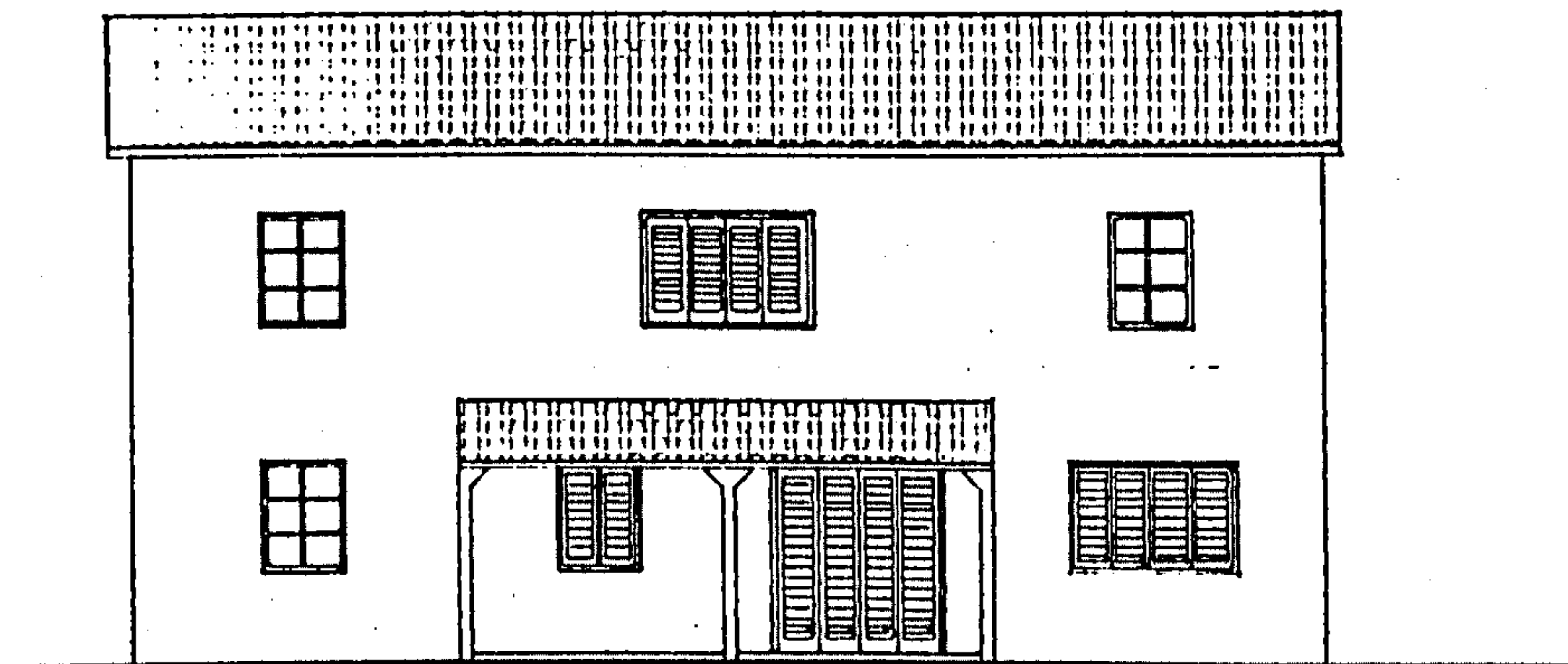
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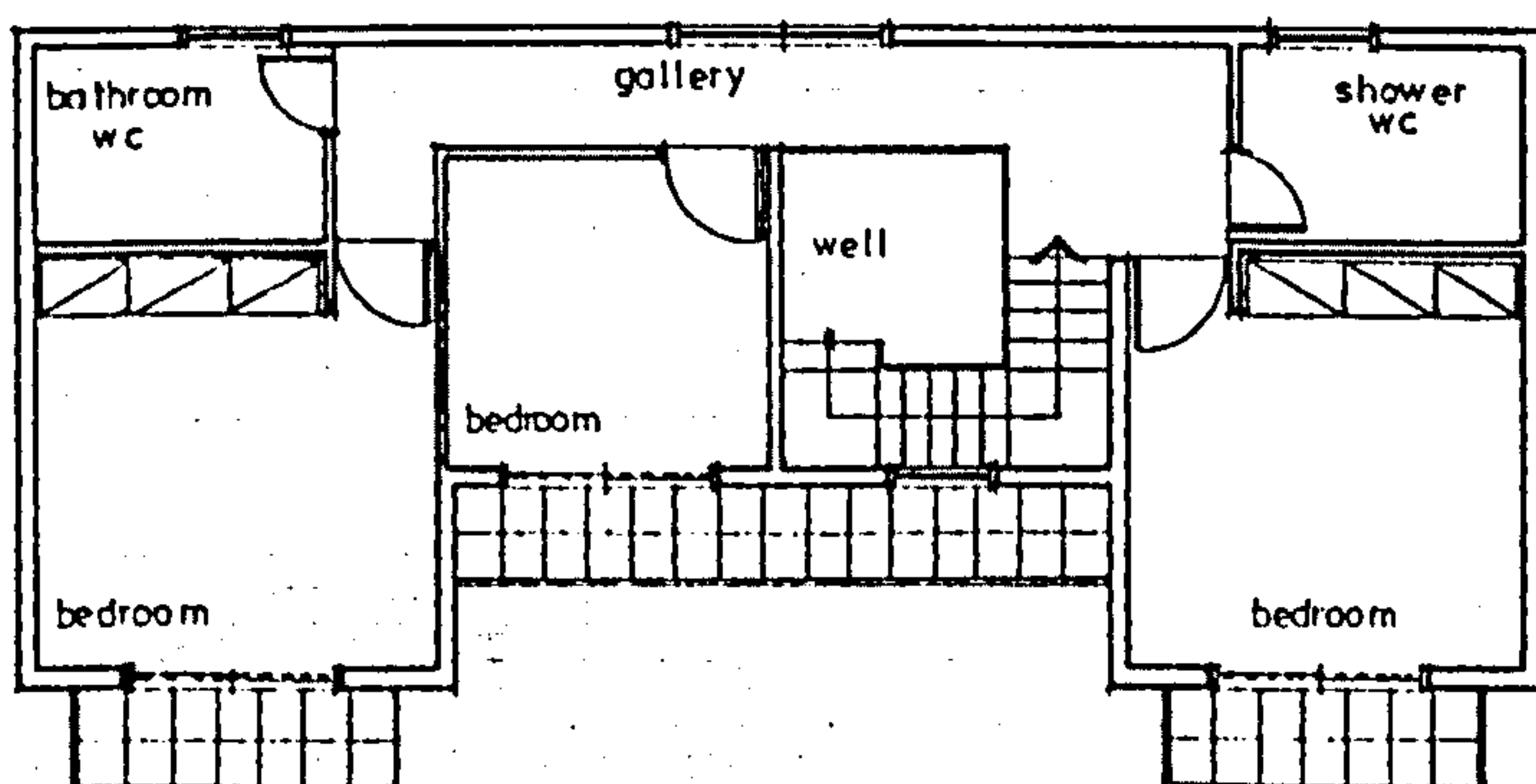
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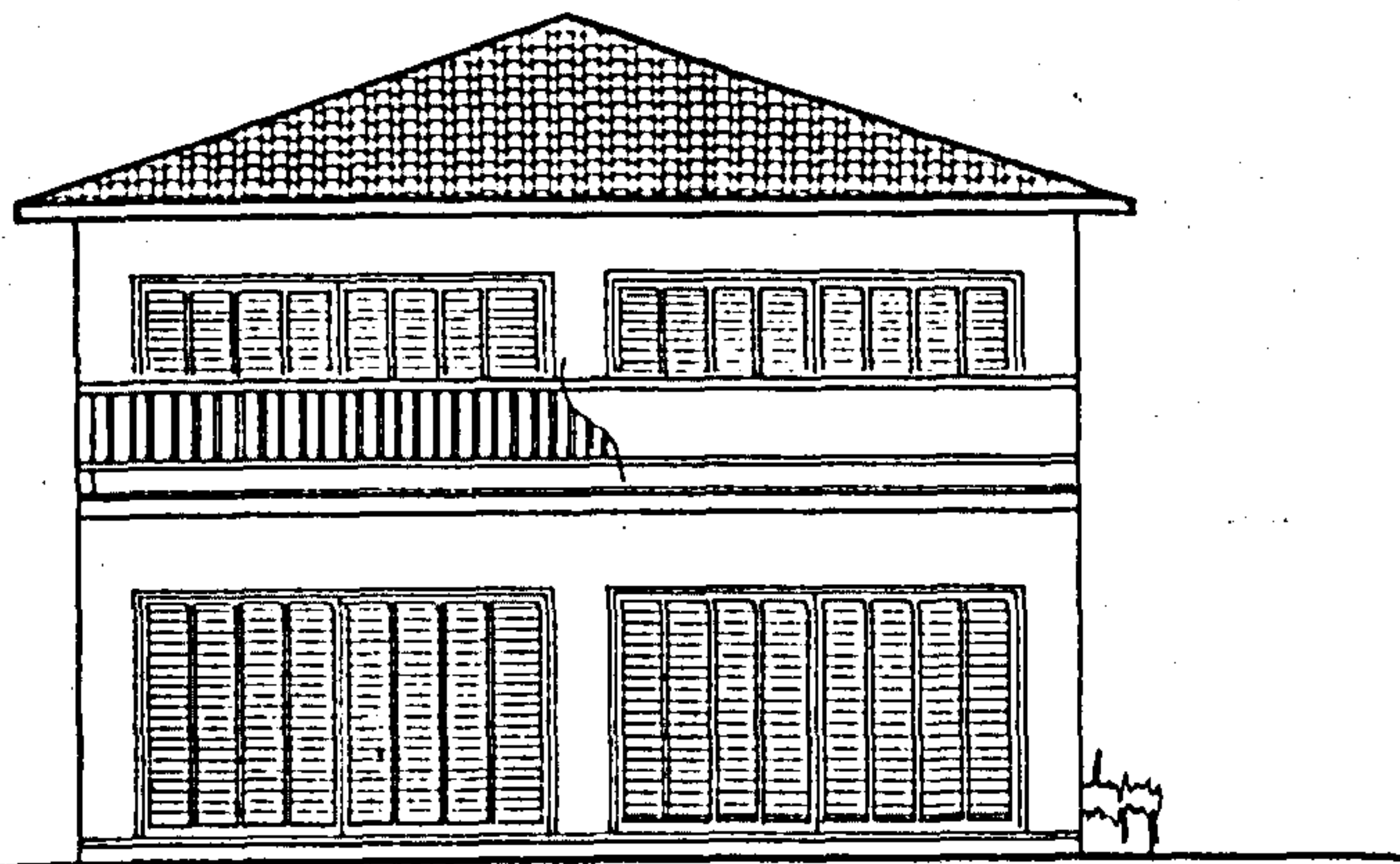
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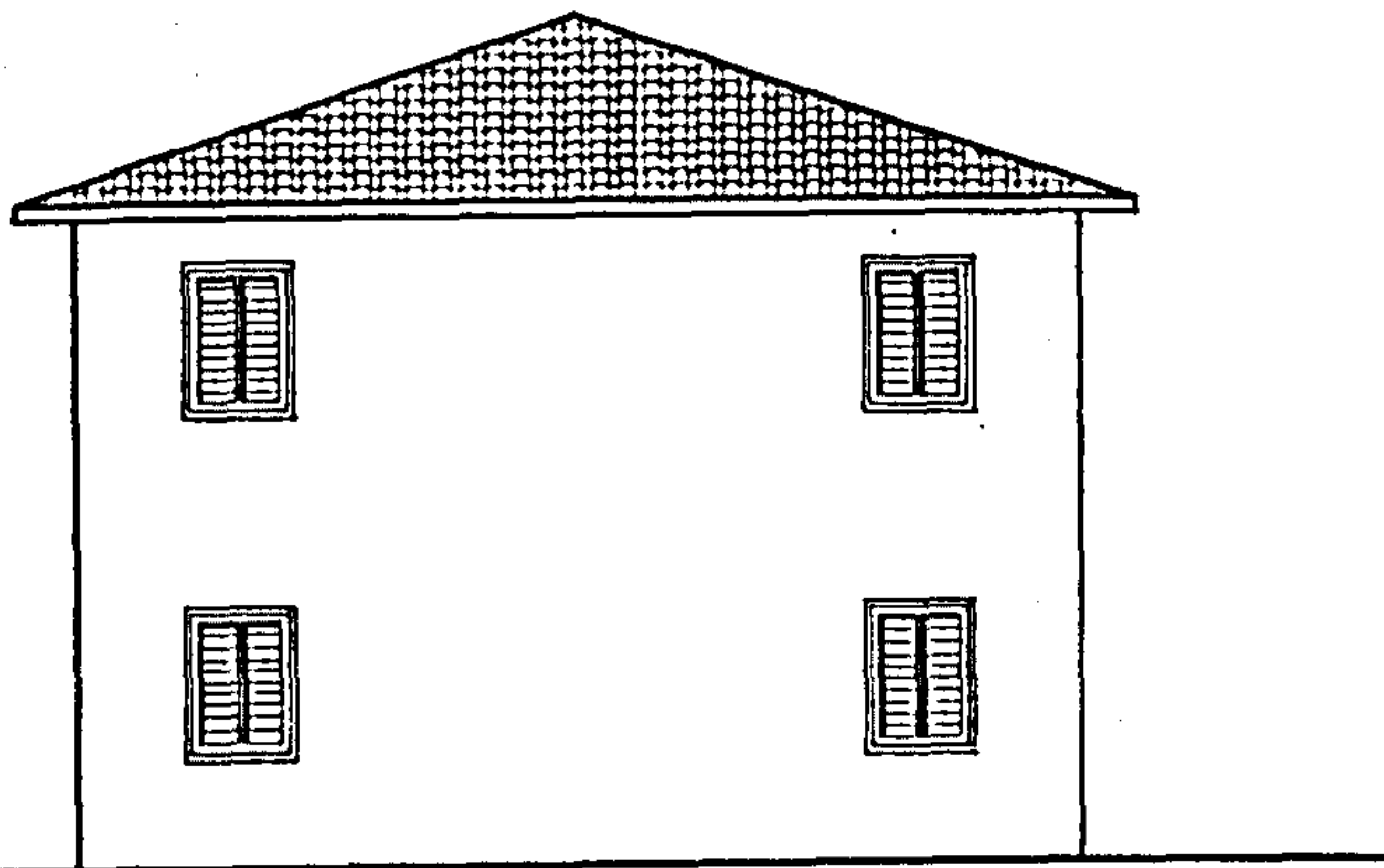
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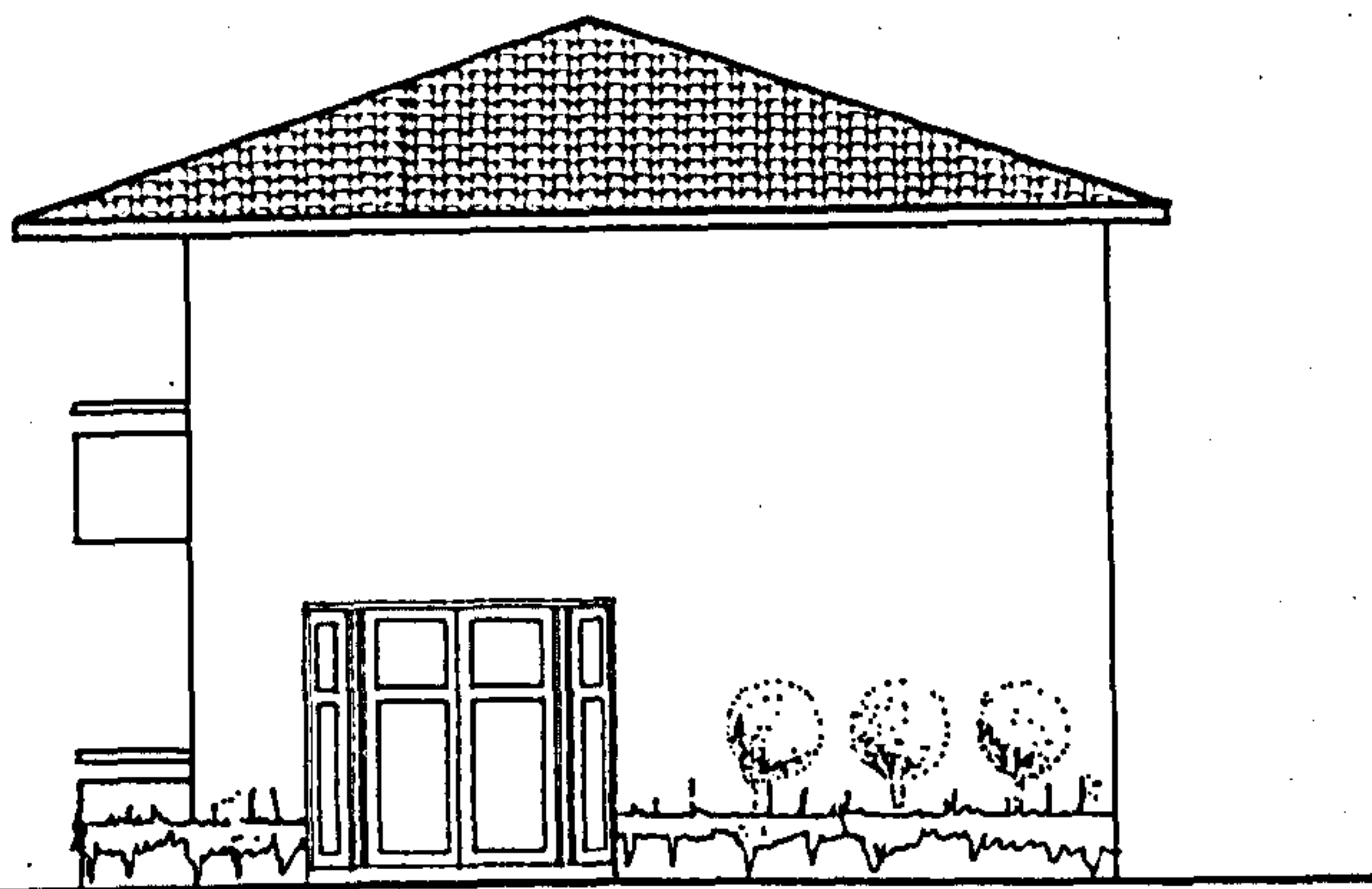




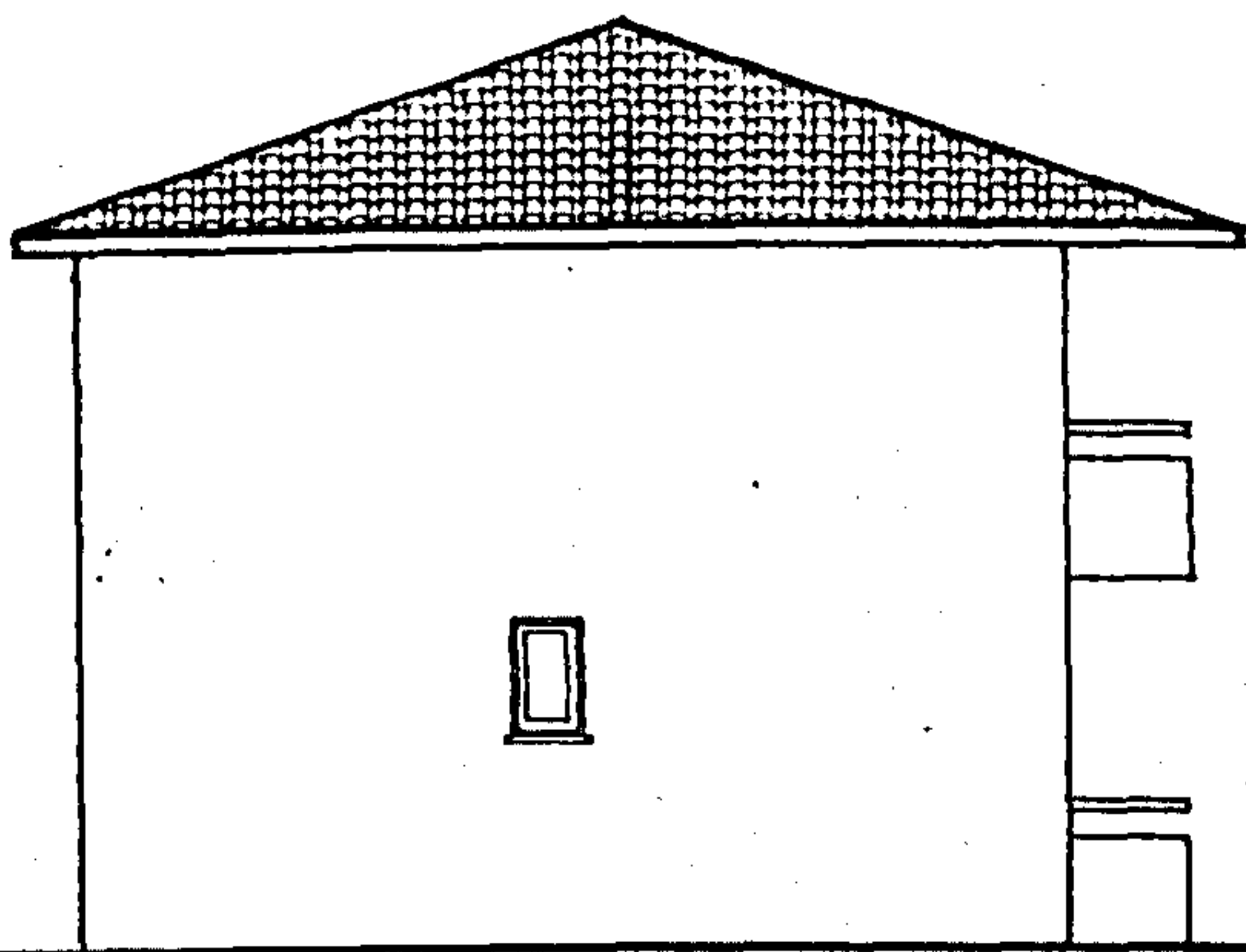
SOUTH ELEVATION



NORTH ELEVATION



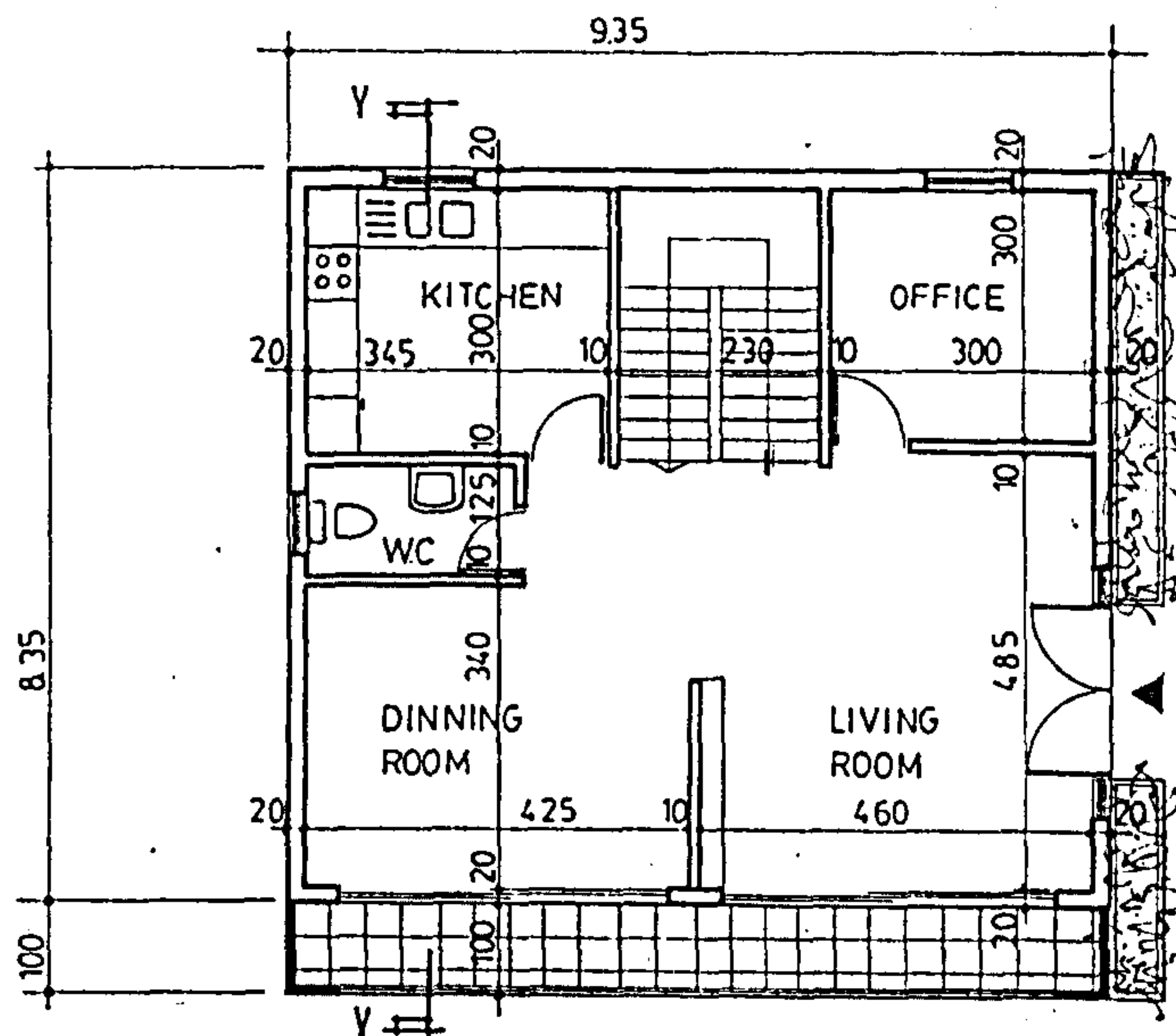
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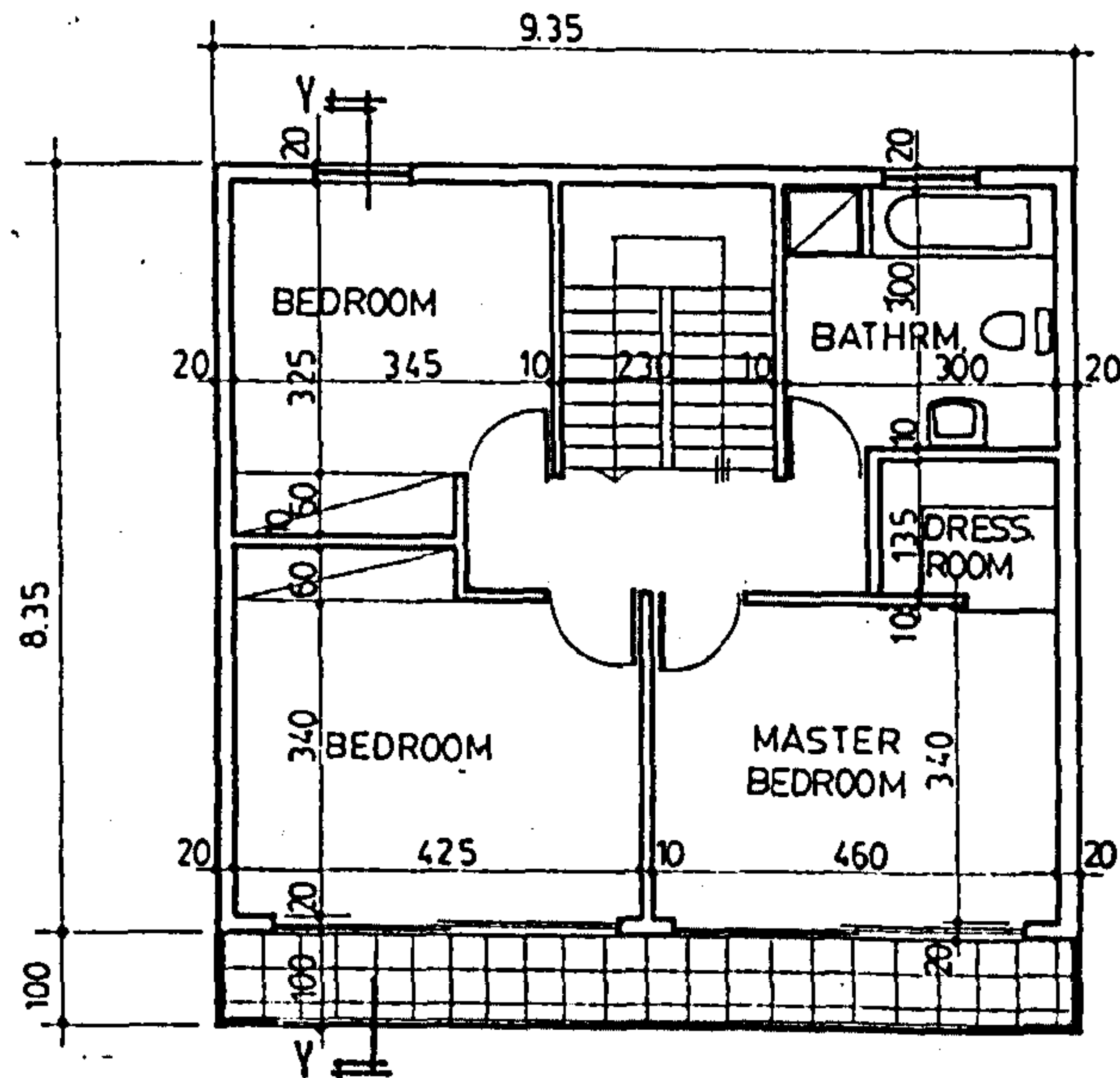
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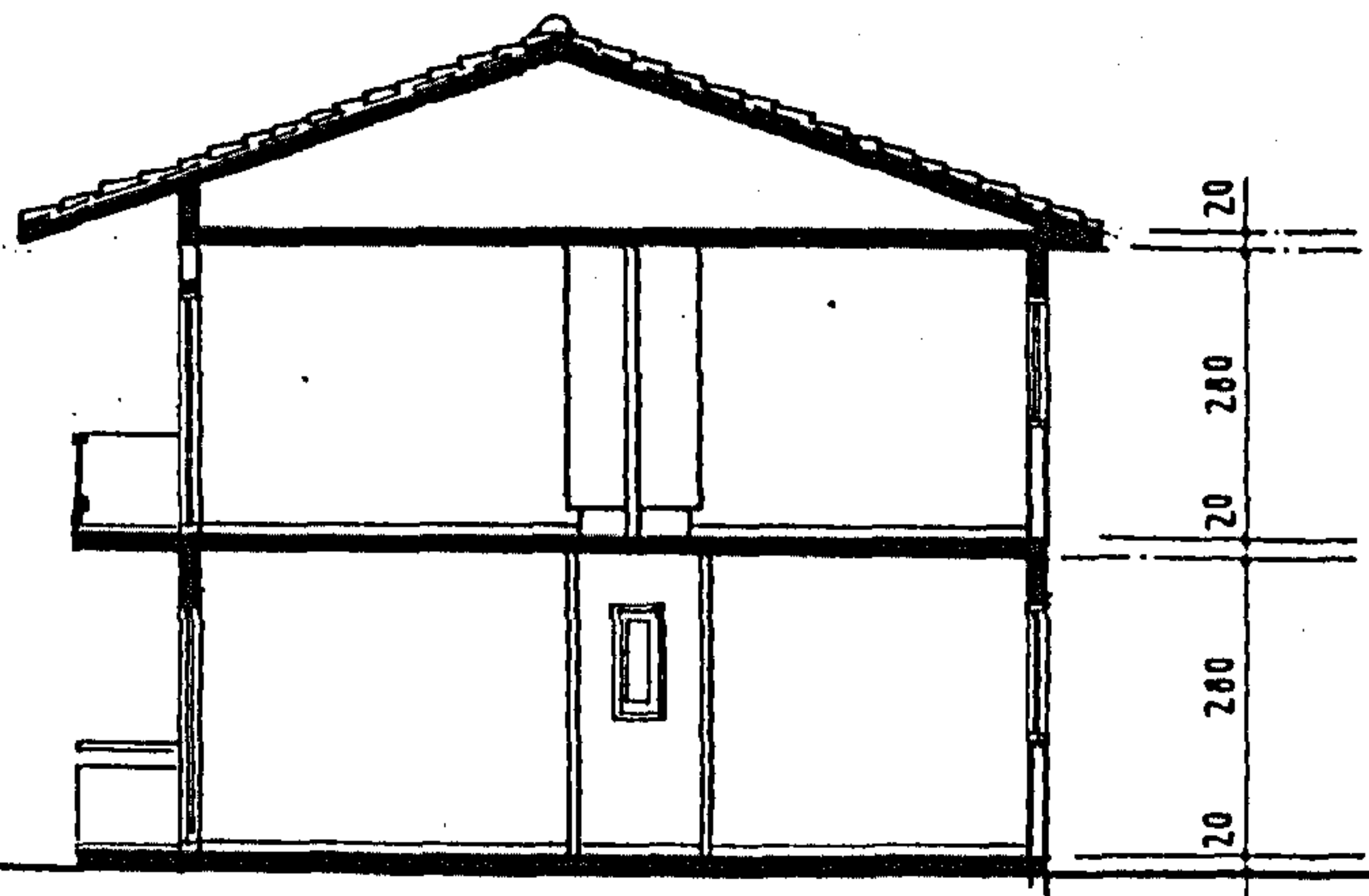
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GROUND FLOOR



FIRST FLOOR



SECTION Y-Y

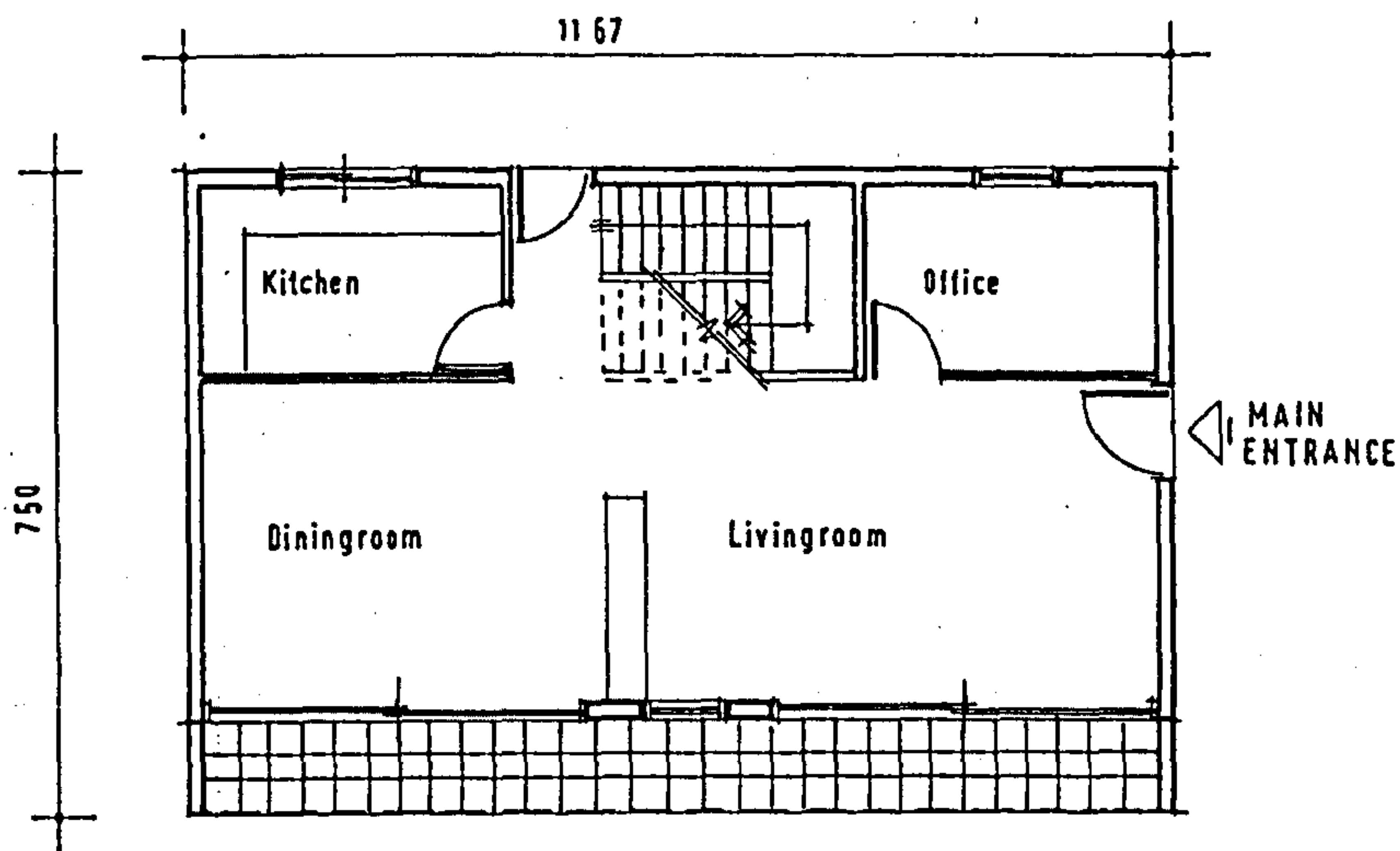


## RECTANGULAR - SHAPE HOUSE 2

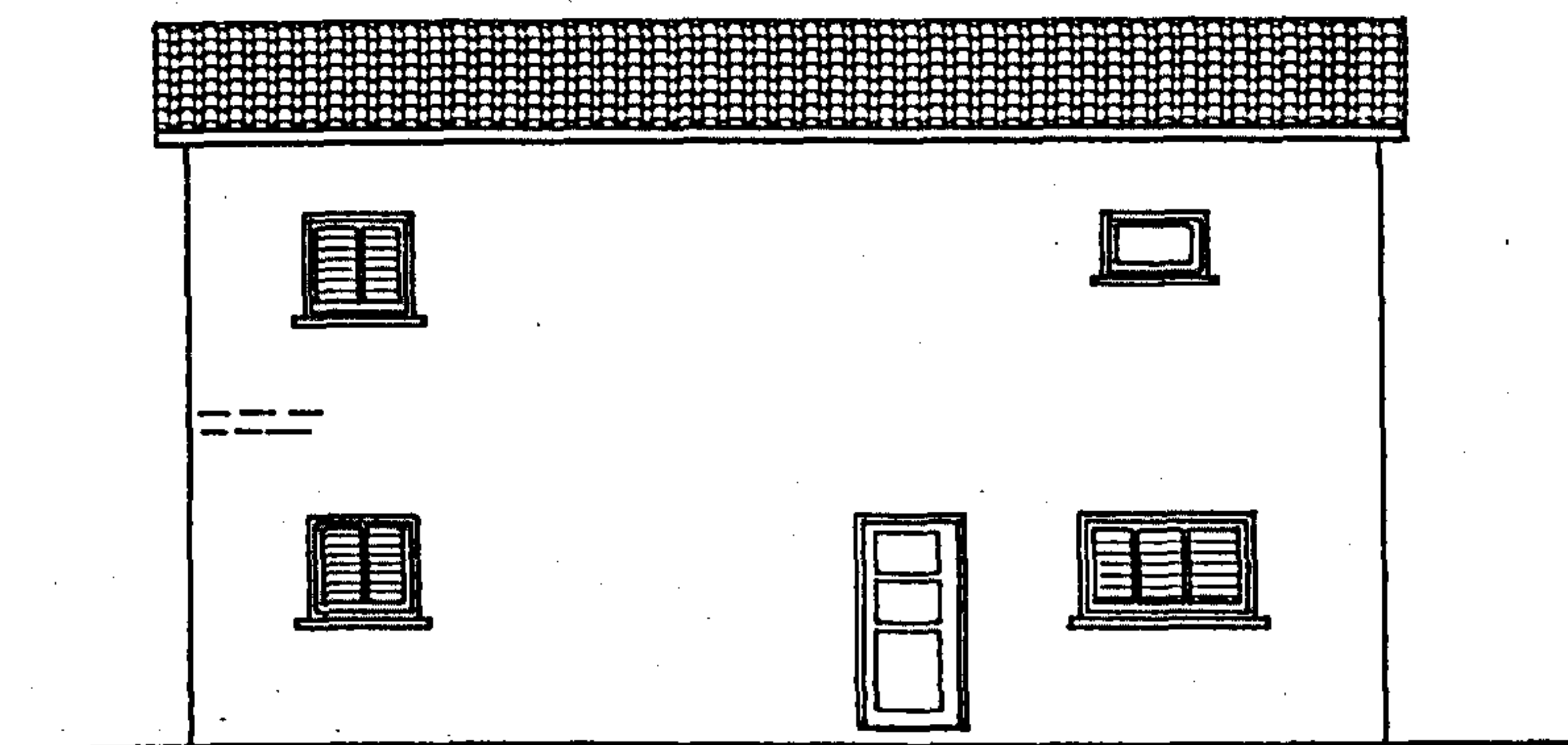
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-Section

DWG:5

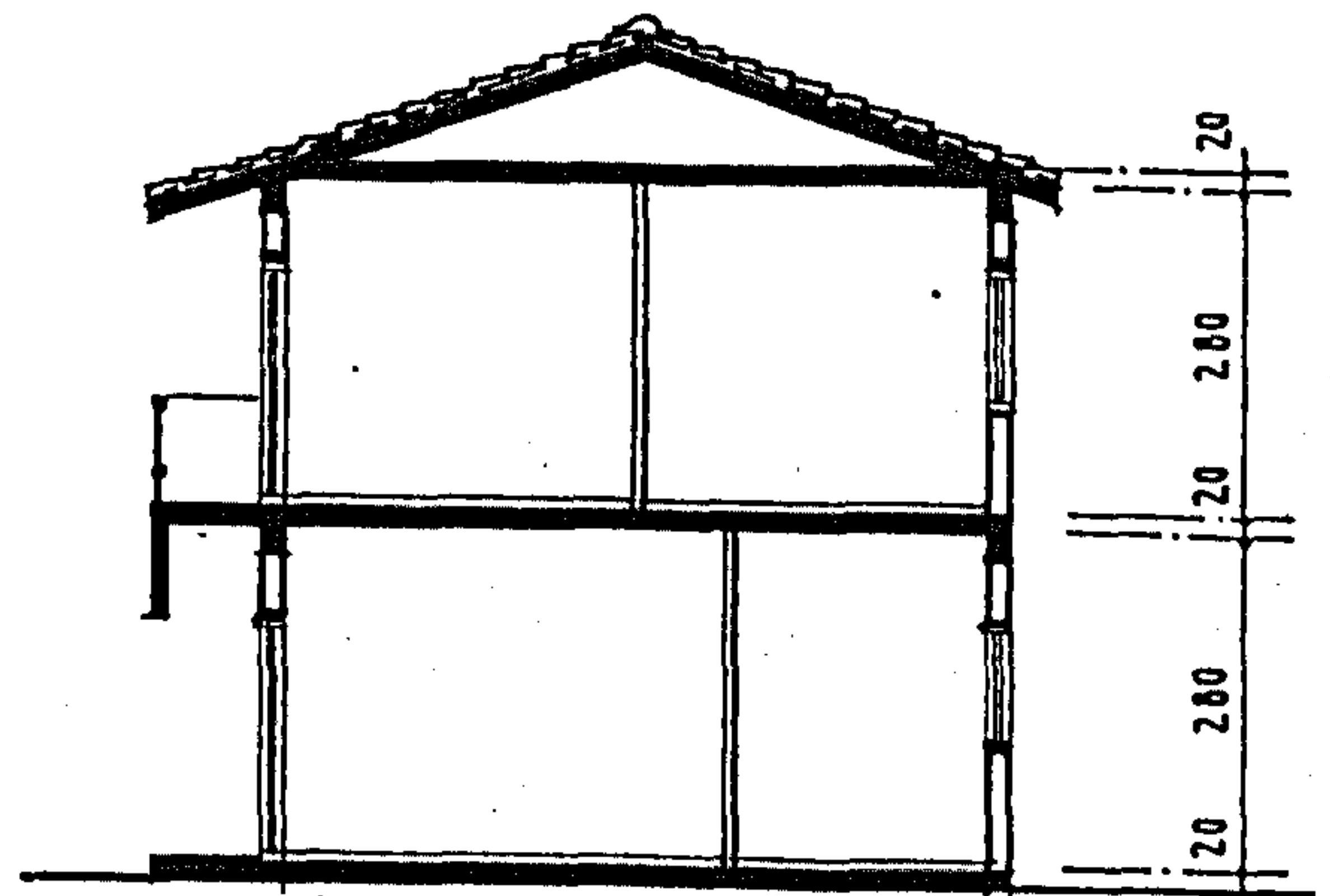
FRONT ELEVATION



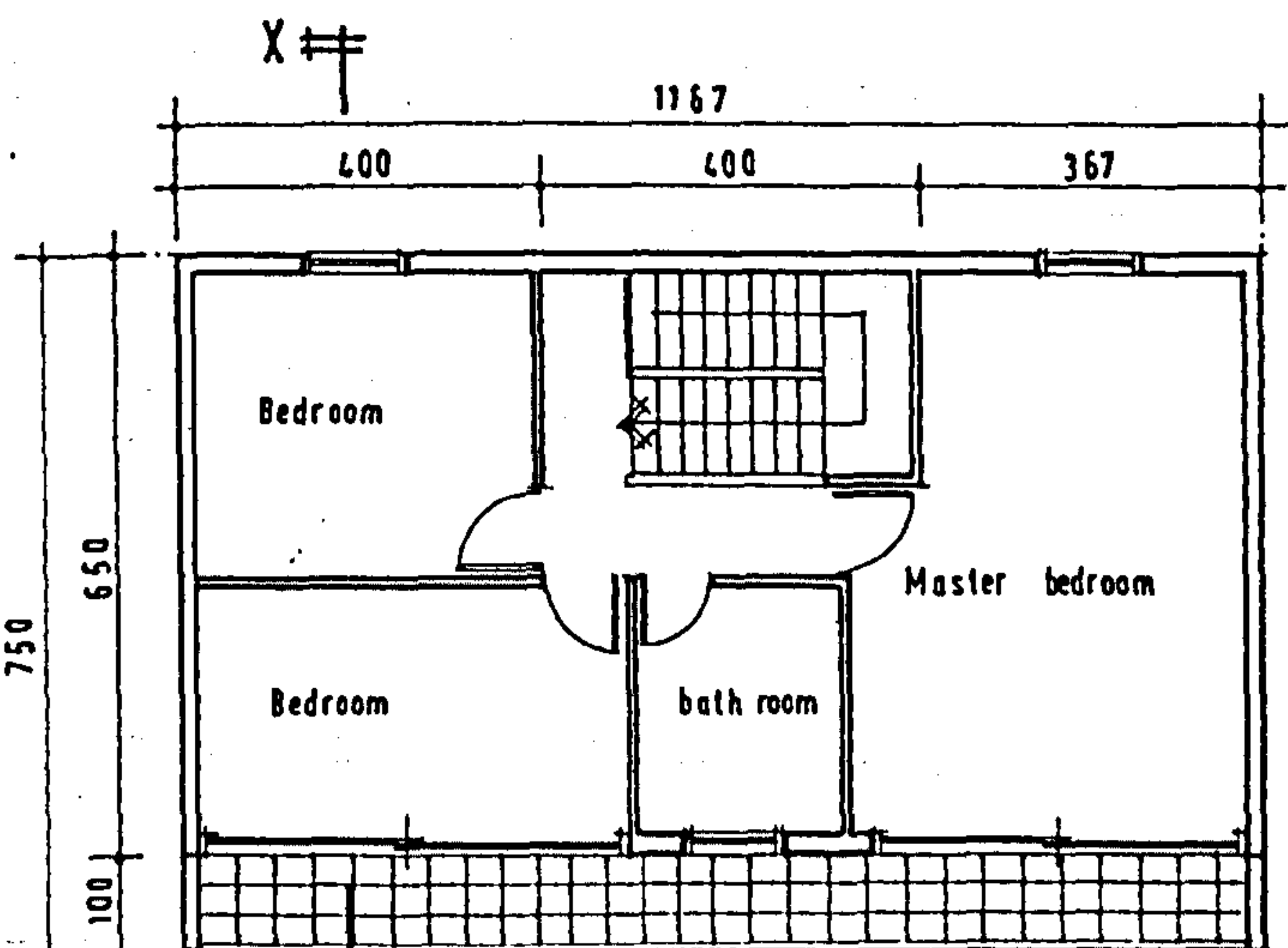
GROUND FLOOR



REAR ELEVATION



SECTION X-X



FIRST FLOOR



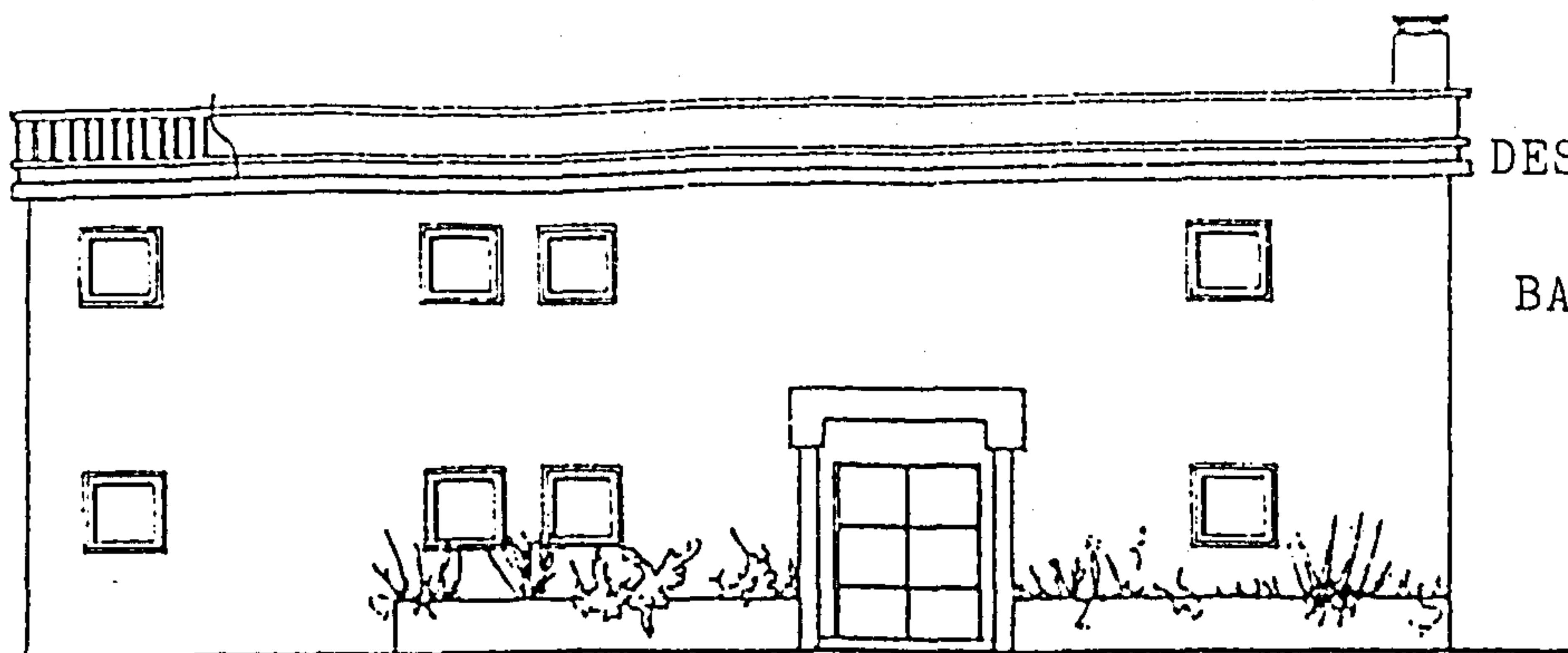
# APPENDICES



## **APPENDIX 3.3.0**

### **BUILDING SIMULATIONS - MAIN DRAWINGS**



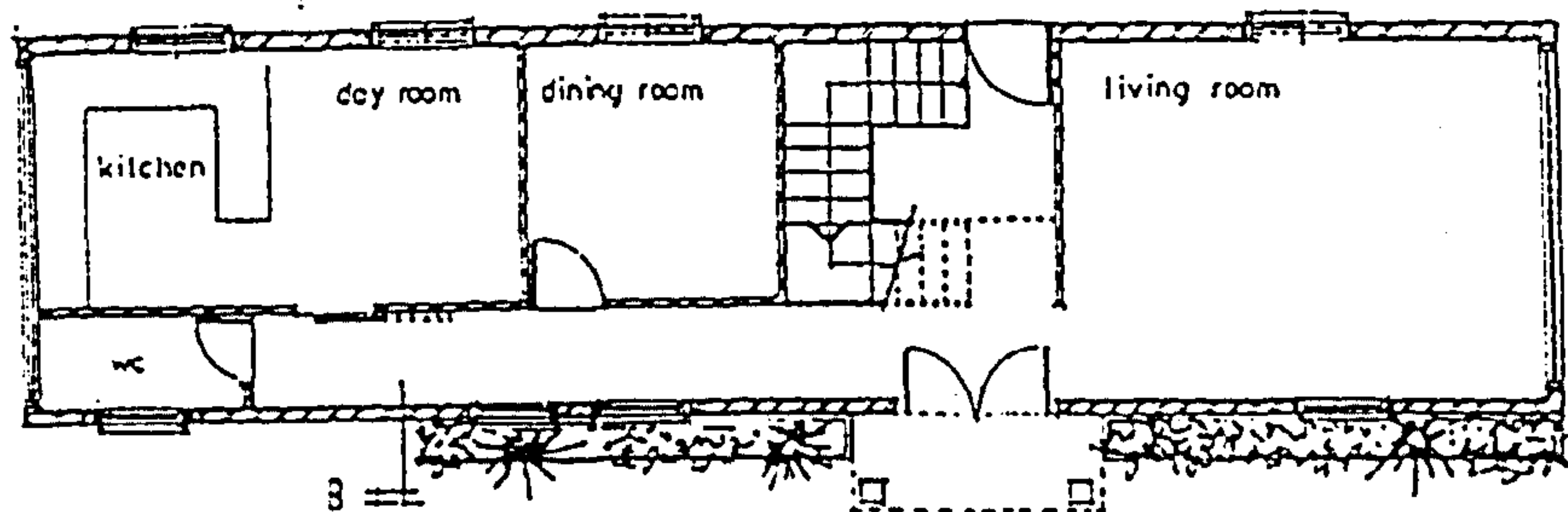


TEST NO: RA  
DESIGN PARAMETER:NONE

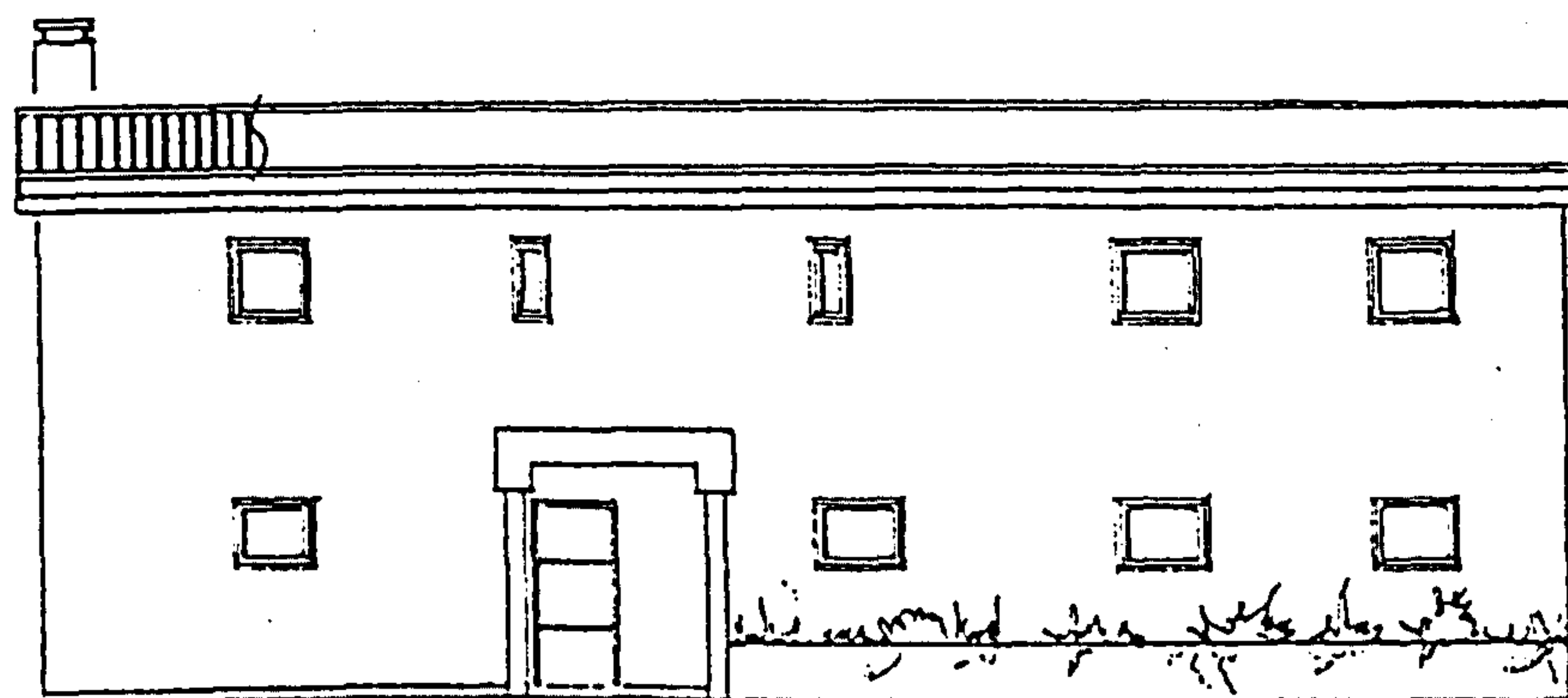
BASE\_CASE

FRONT ELEVATION

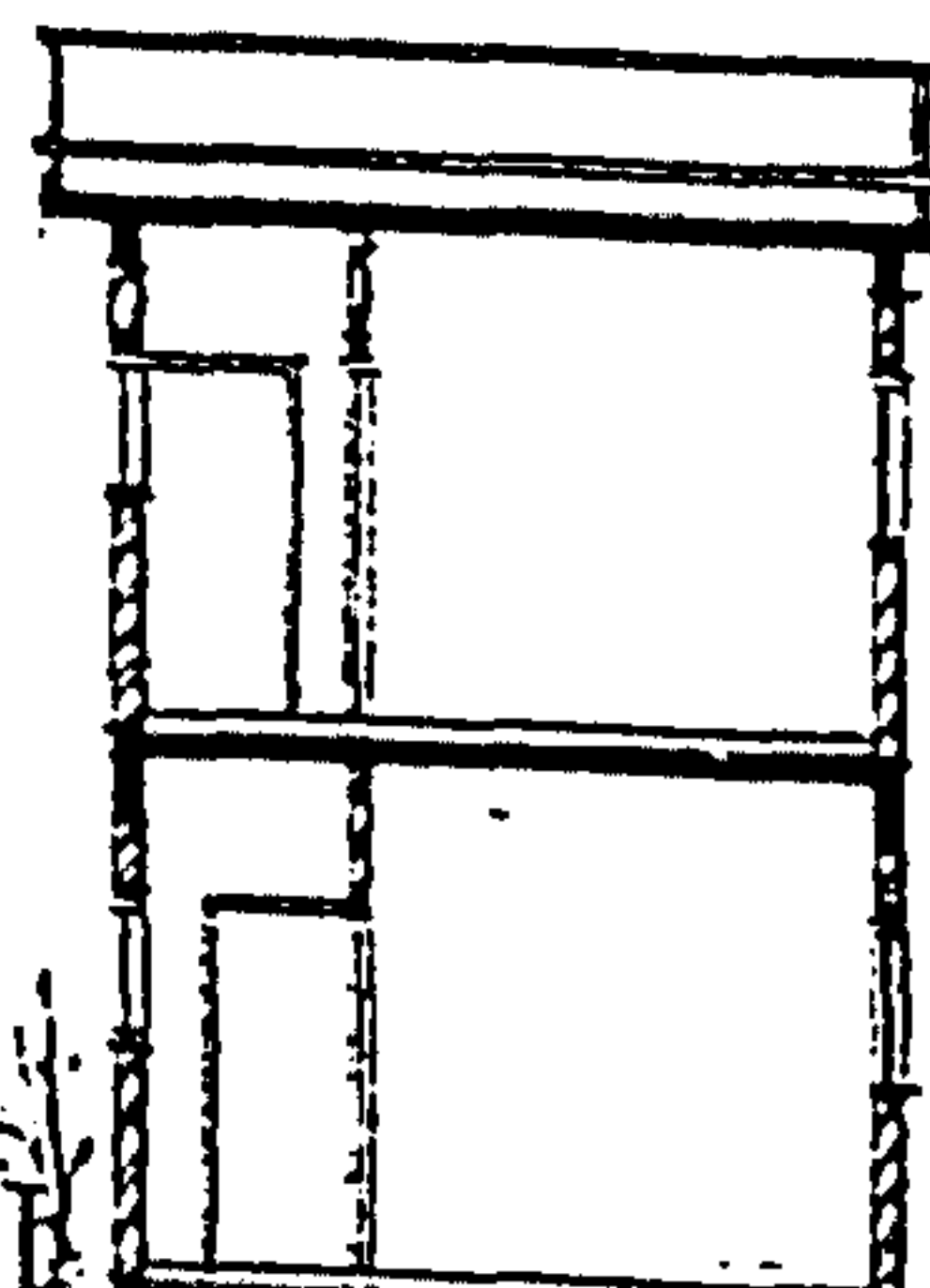
3



GROUND FLOOR

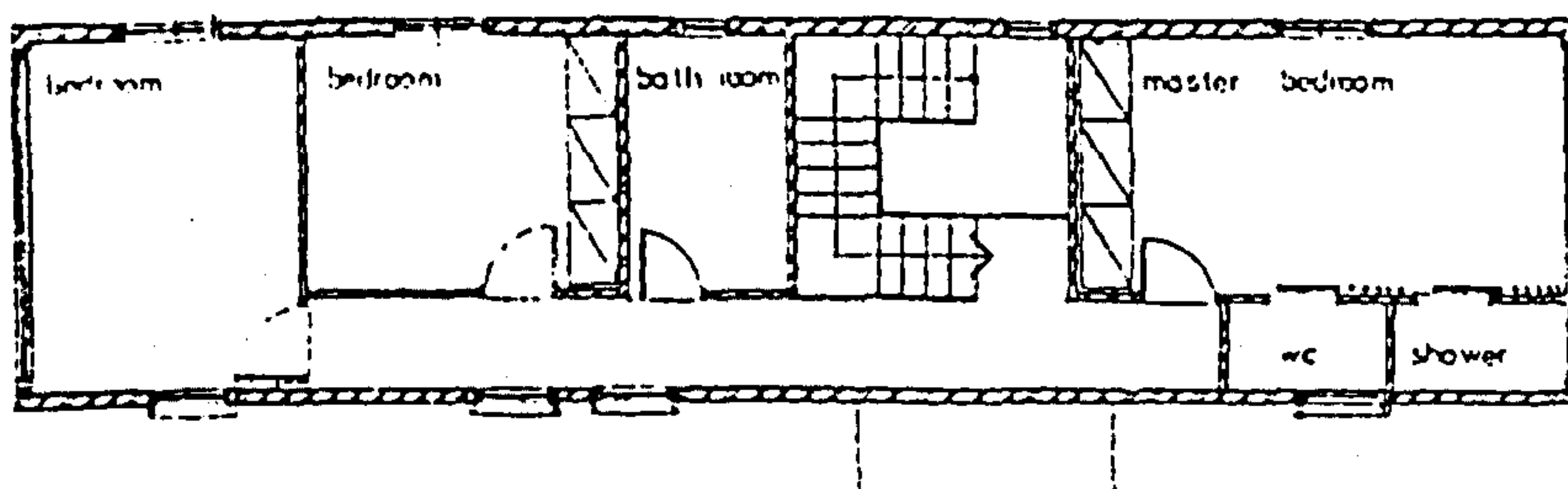


REAR ELEVATION



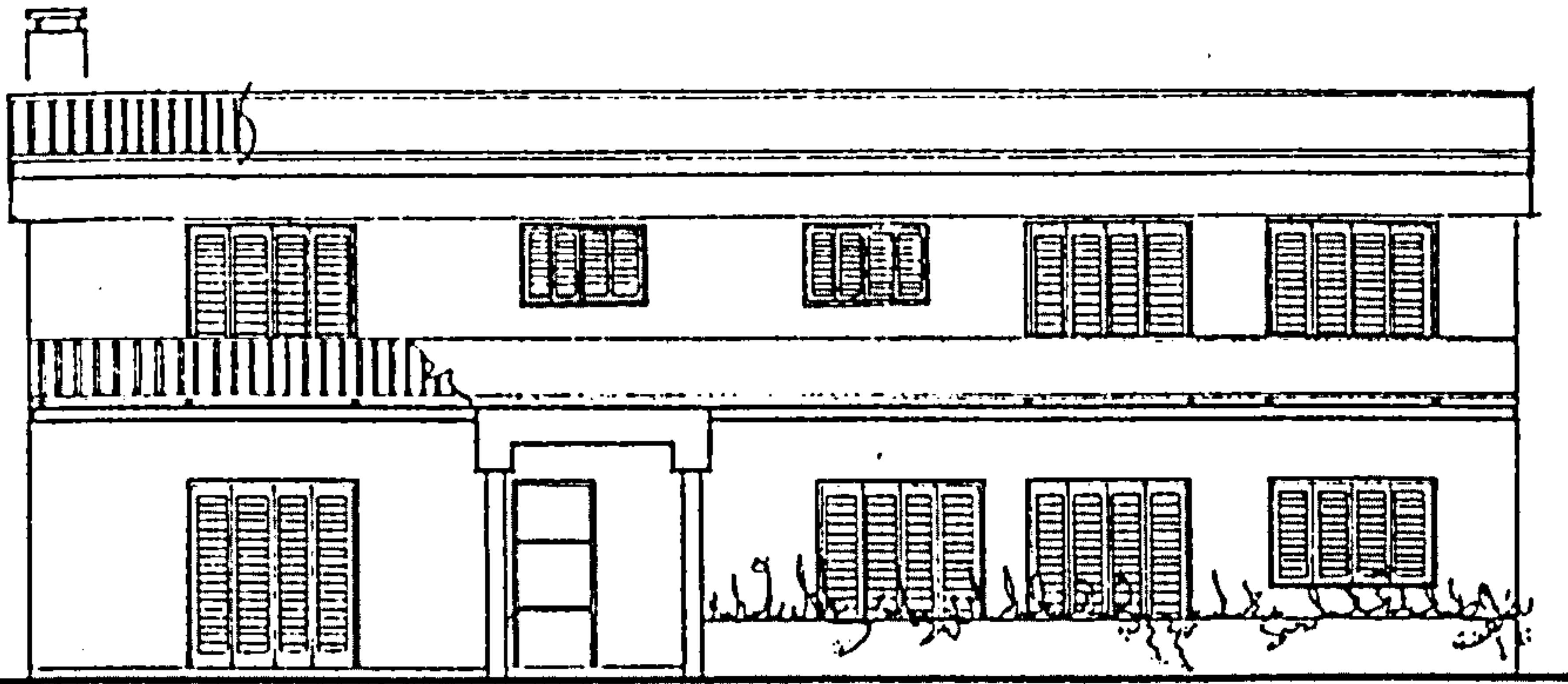
20  
200  
20  
200  
20

SECTION 3-3



FIRST FLOOR

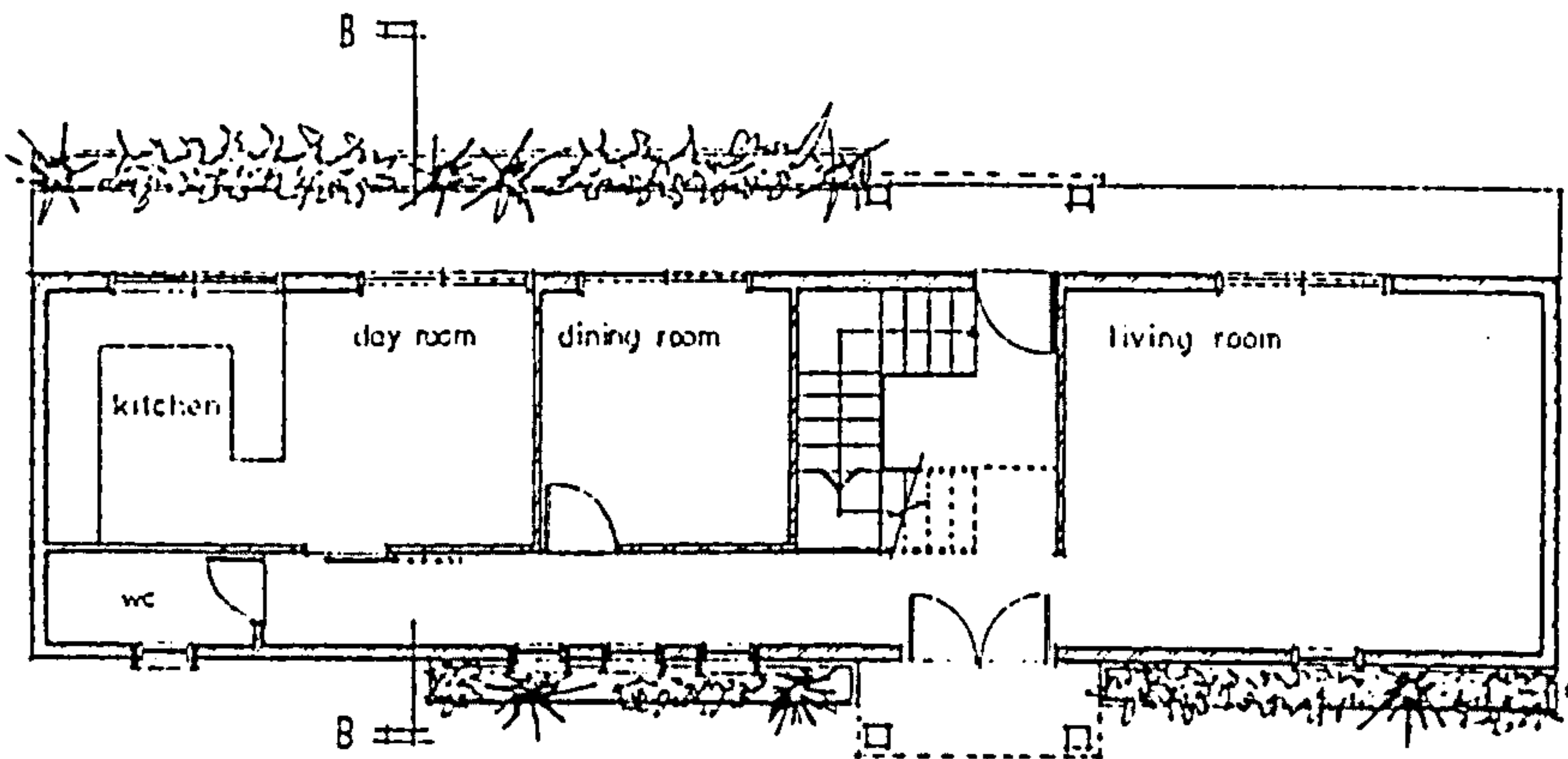




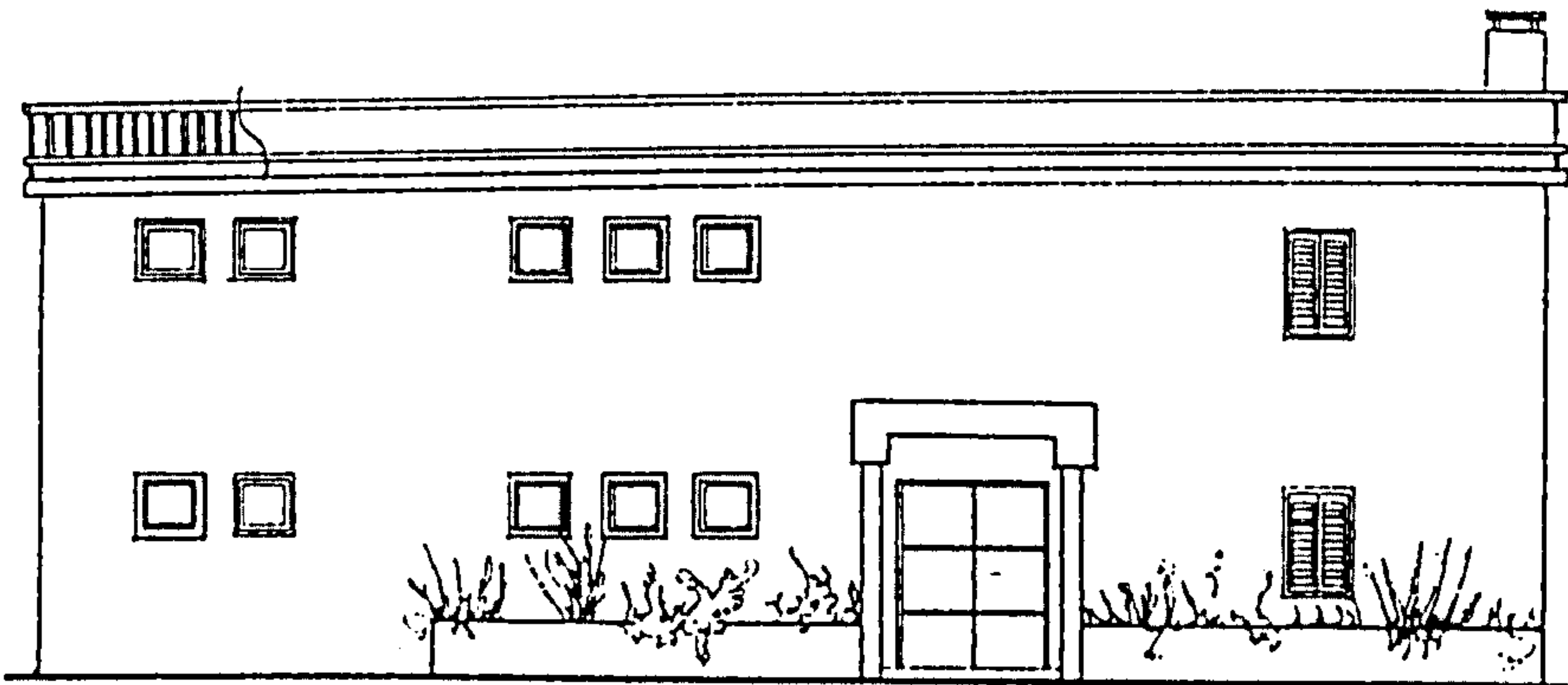
REAR ELEVATION

TEST NO: R1

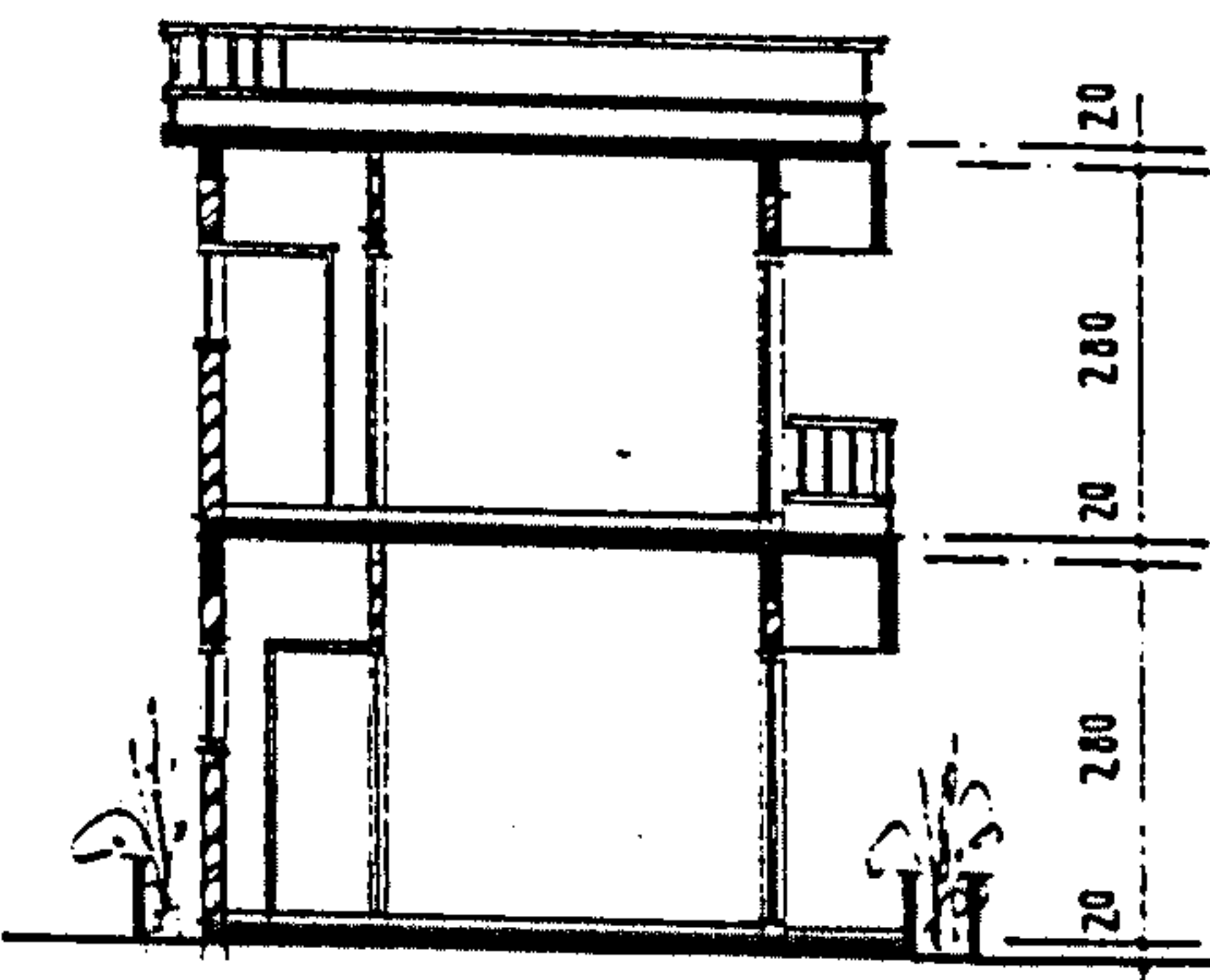
DESIGN PARAMETER: SHAPE



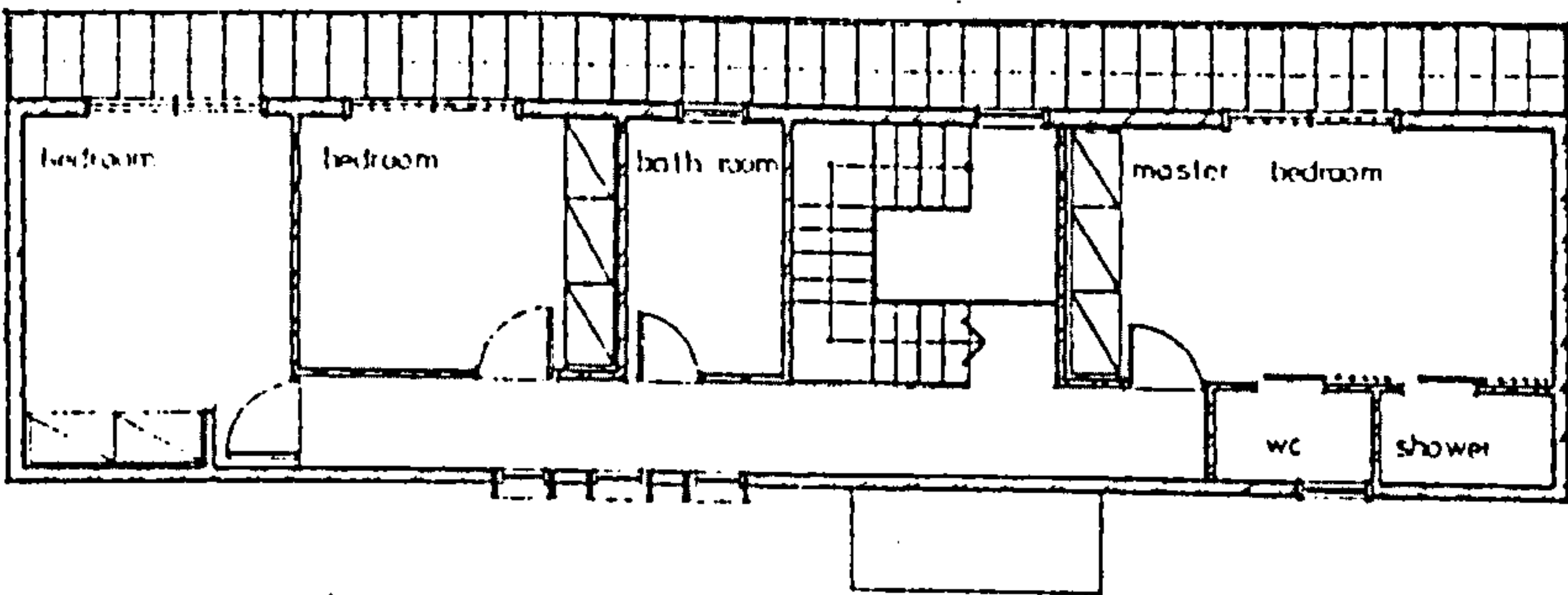
GROUND FLOOR



FRONT ELEVATION

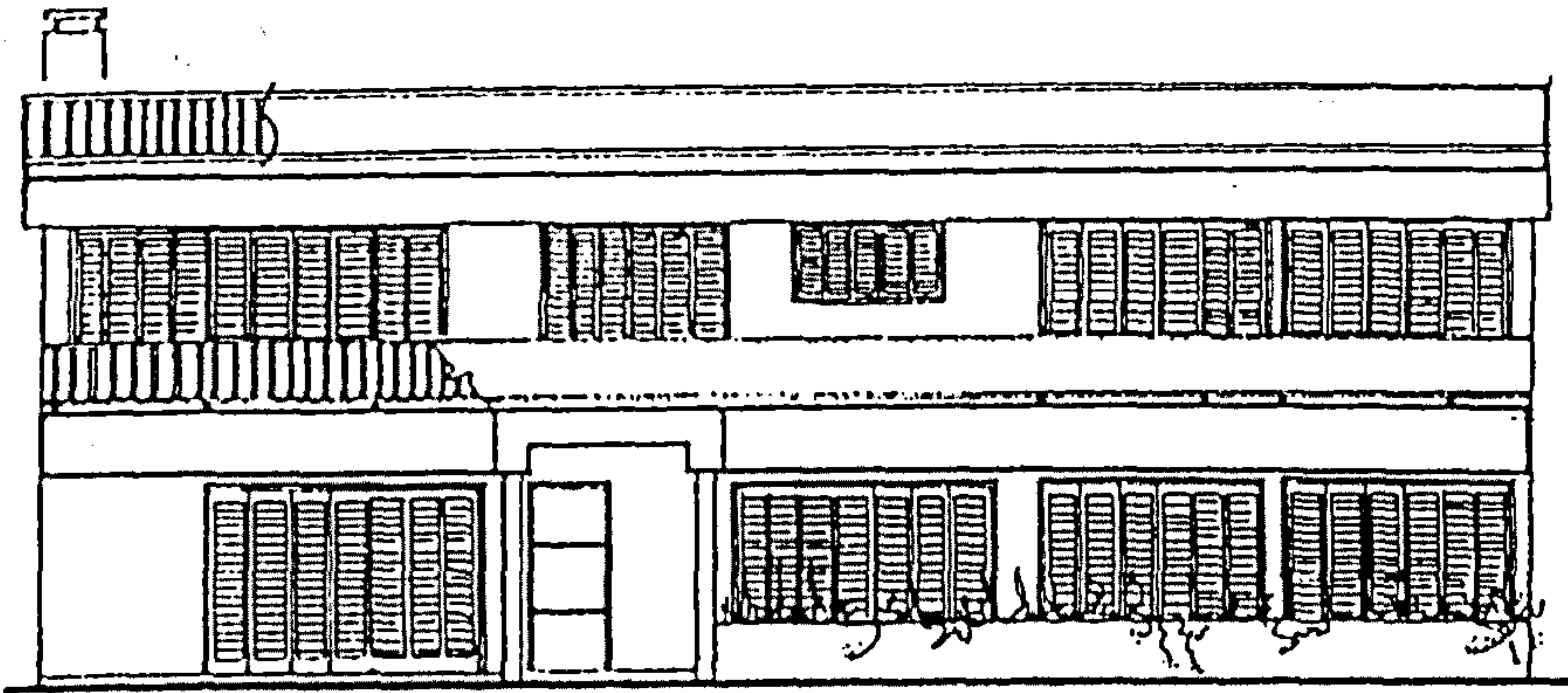


SECTION B-B



FIRST FLOOR





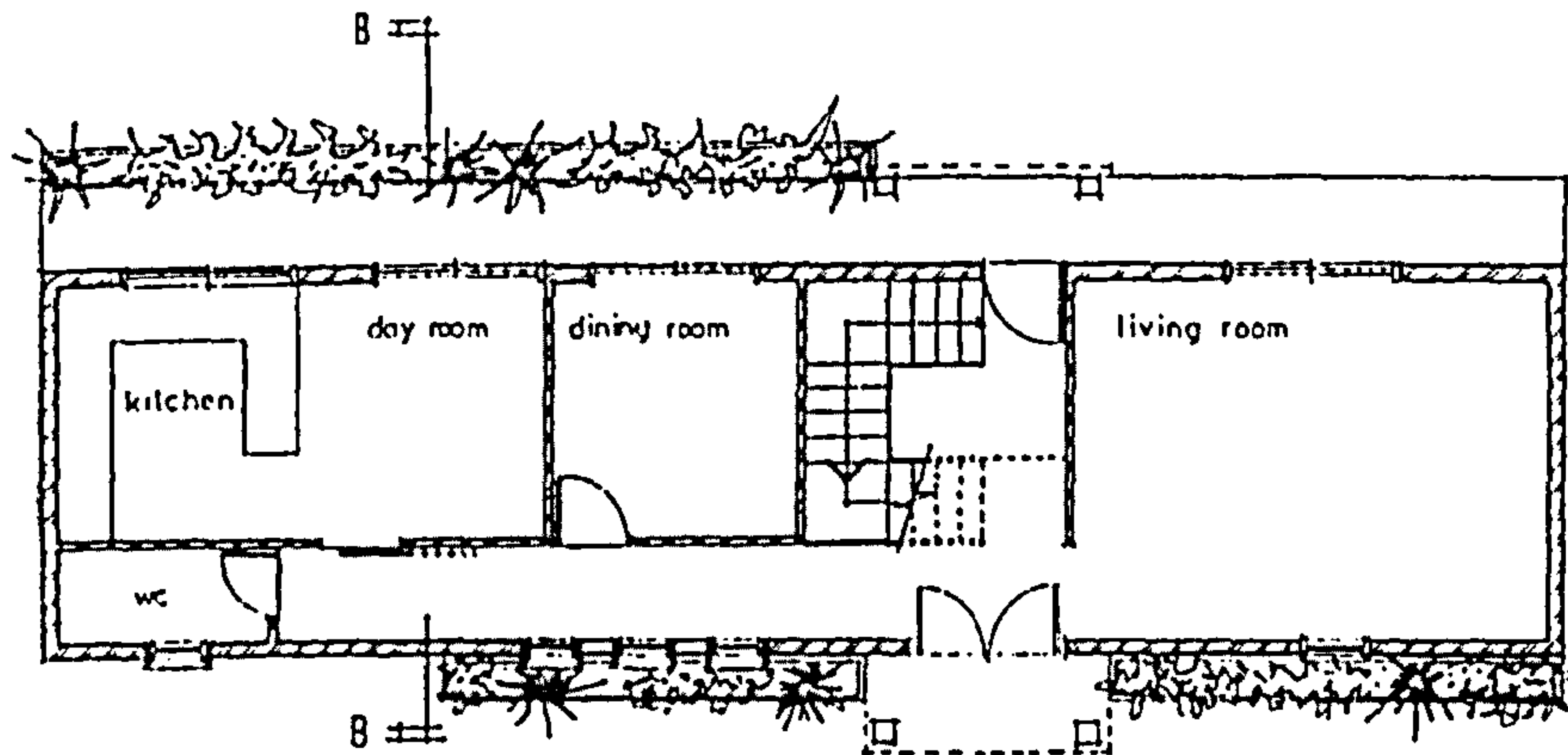
REAR ELEVATION

TEST NO: R2

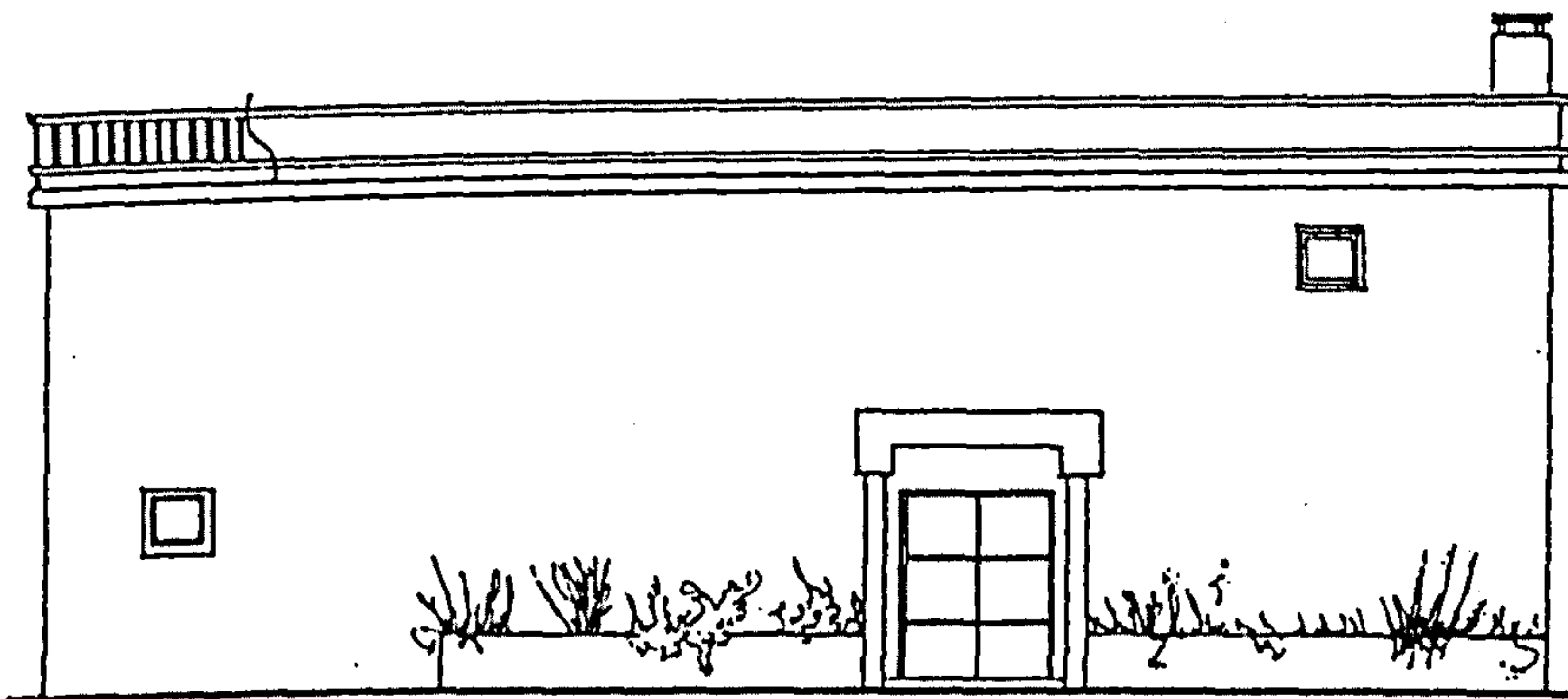
DESIGN PARAMETER:  
GLAZING

STH-Increased by  $30.0\text{m}^2$

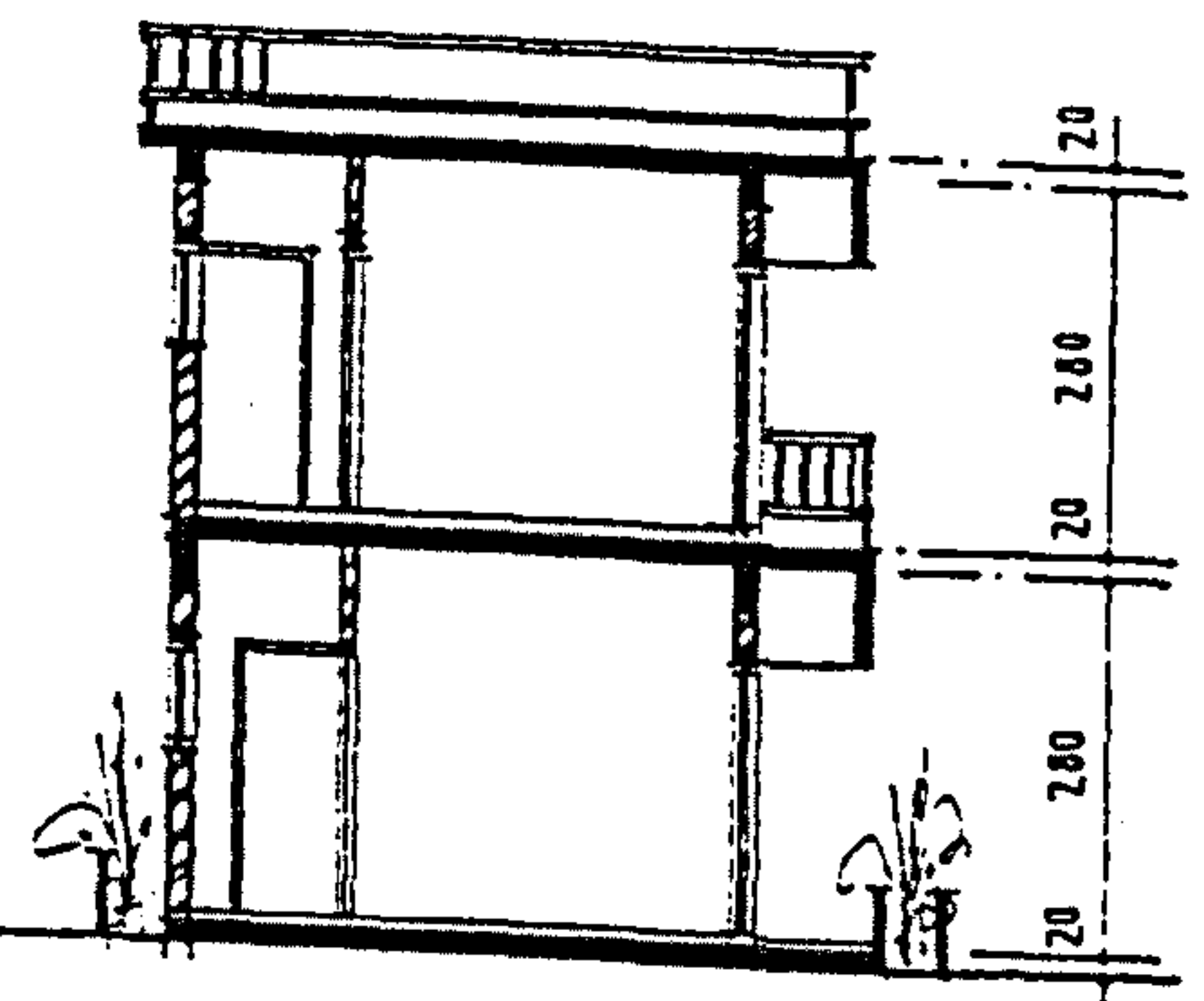
NRTH-Decreased by  $3.0\text{m}^2$



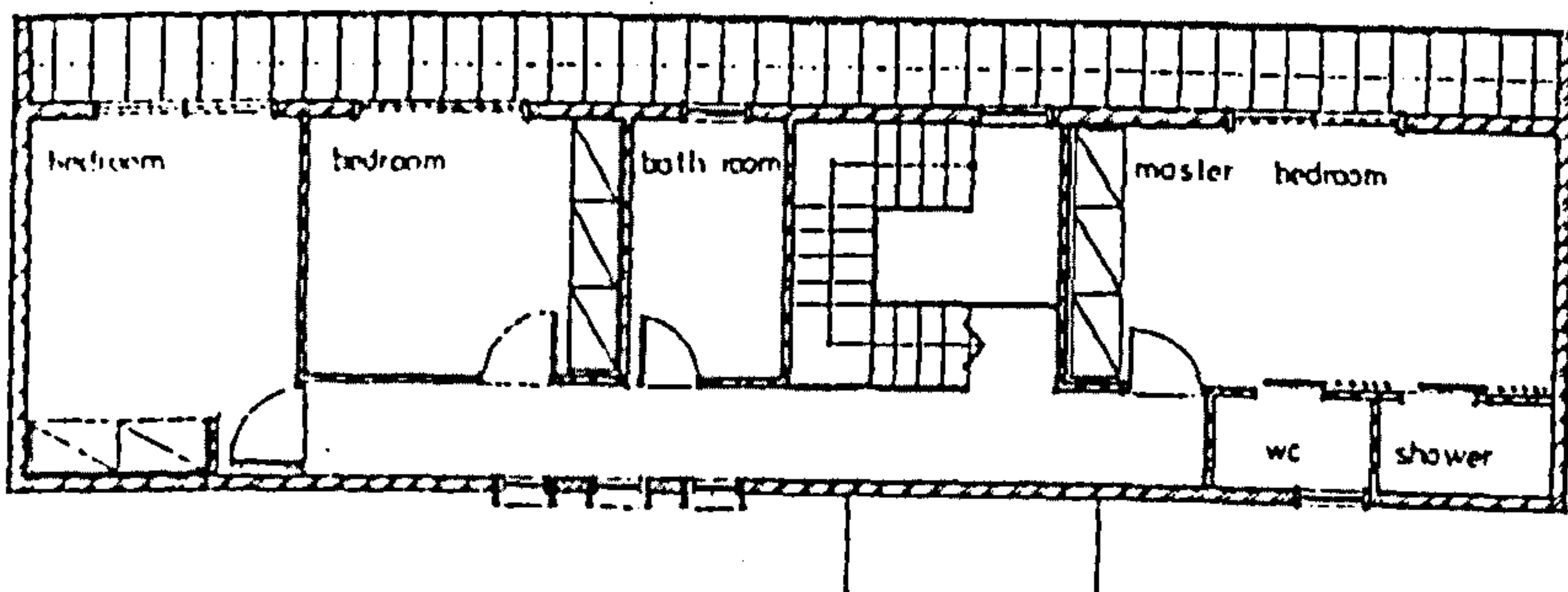
GROUND FLOOR



FRONT ELEVATION



SECTION B-B

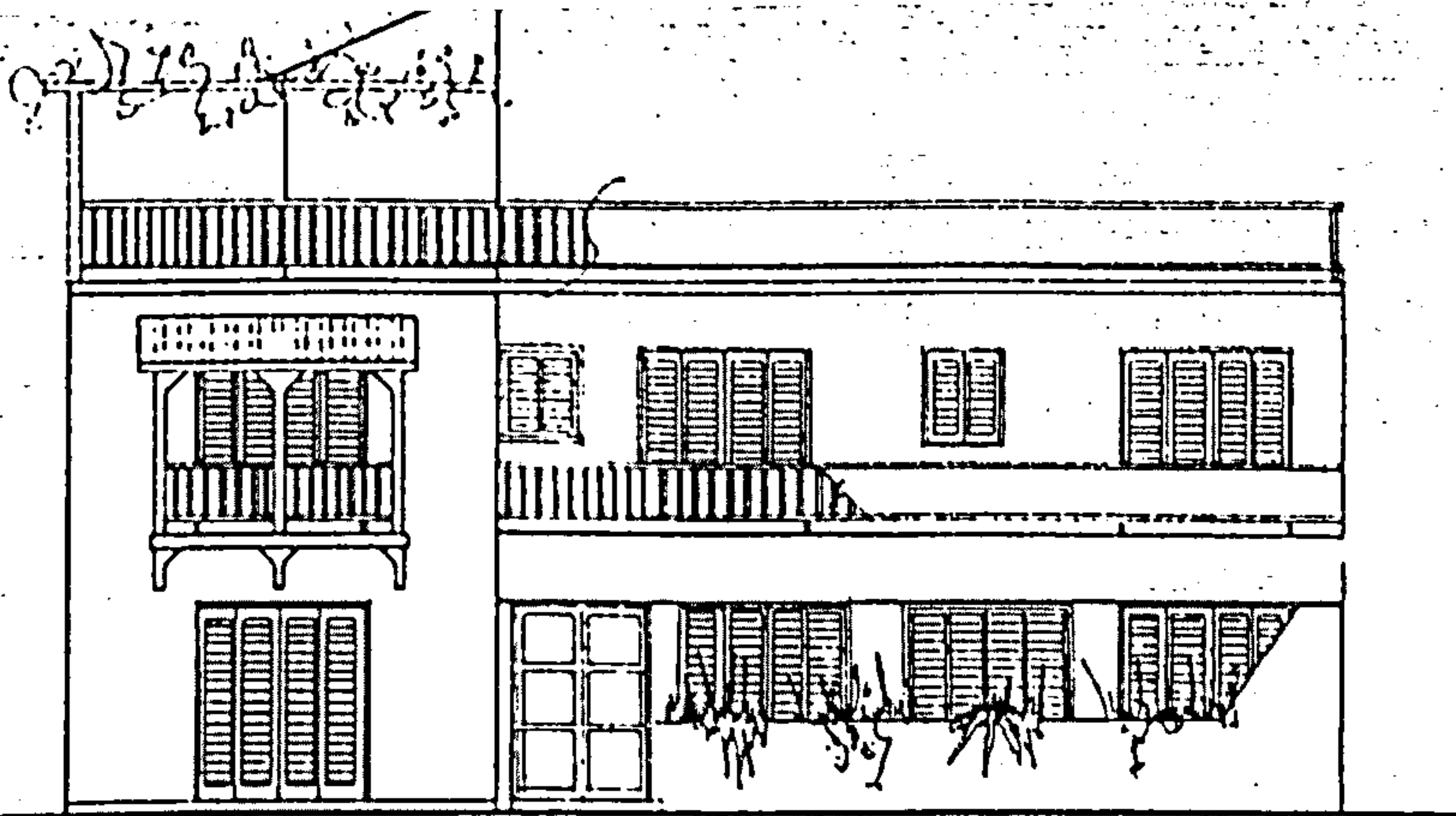


FIRST FLOOR

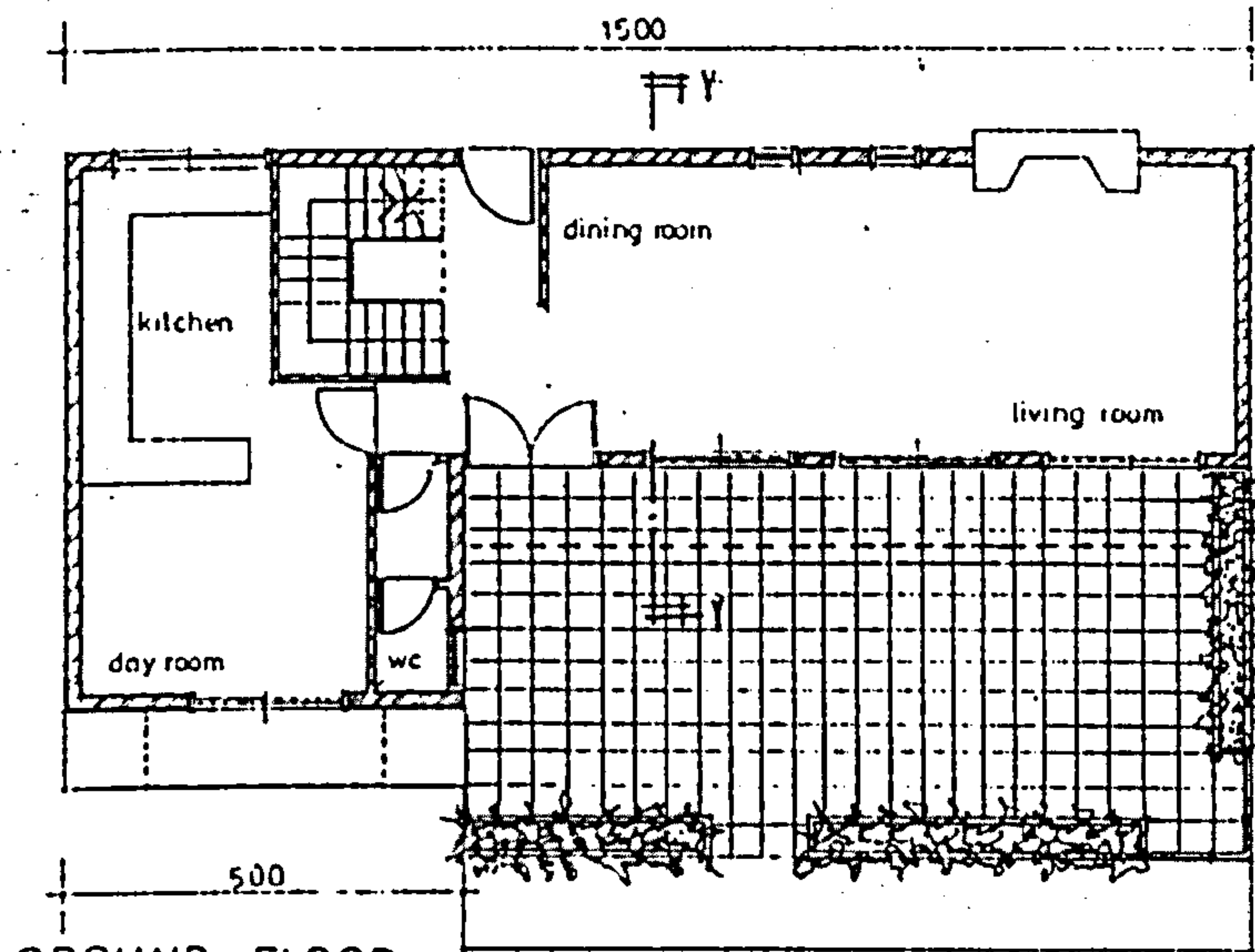


TEST NO: L1

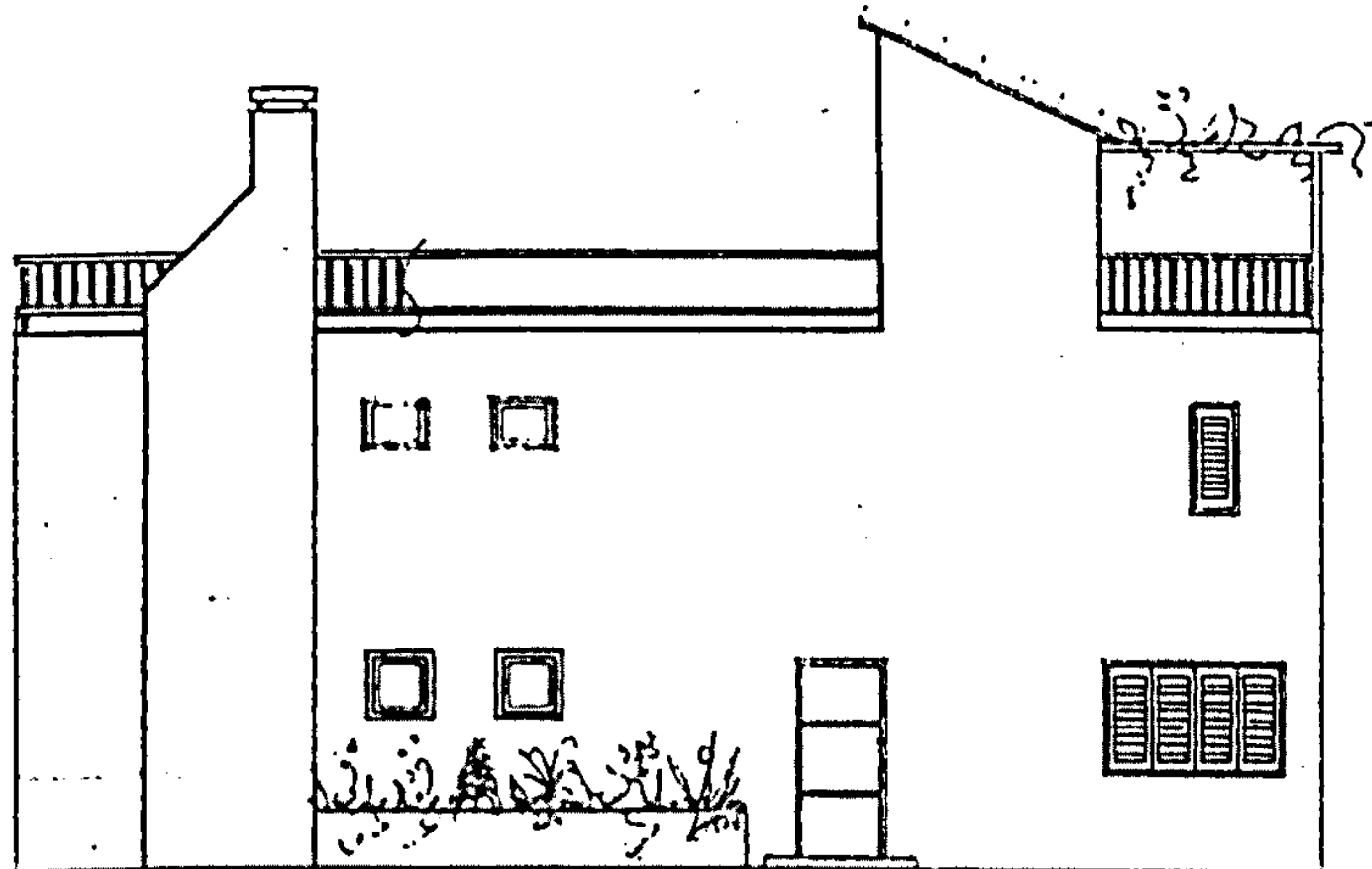
DESIGN PARAMETER: SHAPE -L



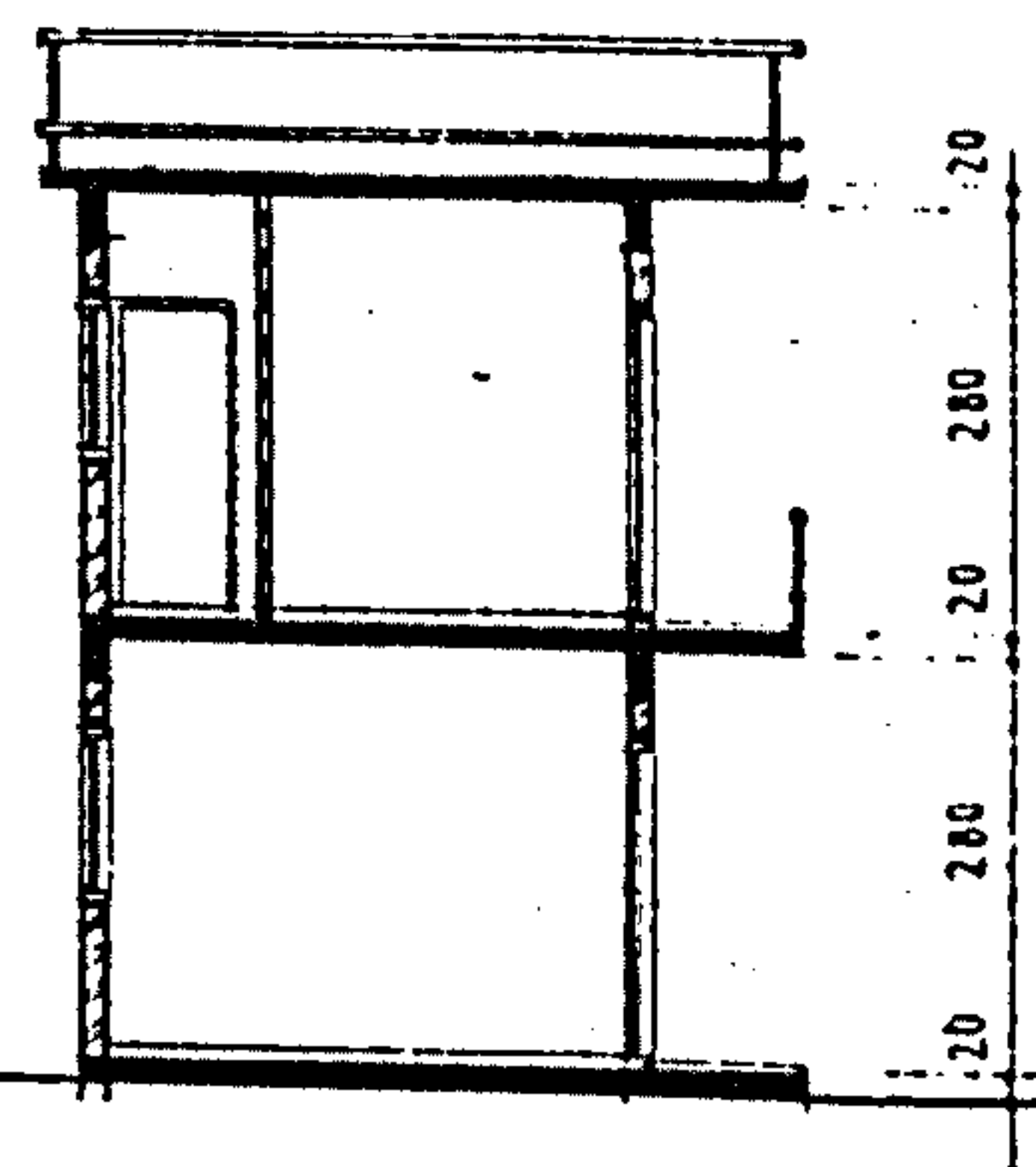
FRONT ELEVATION



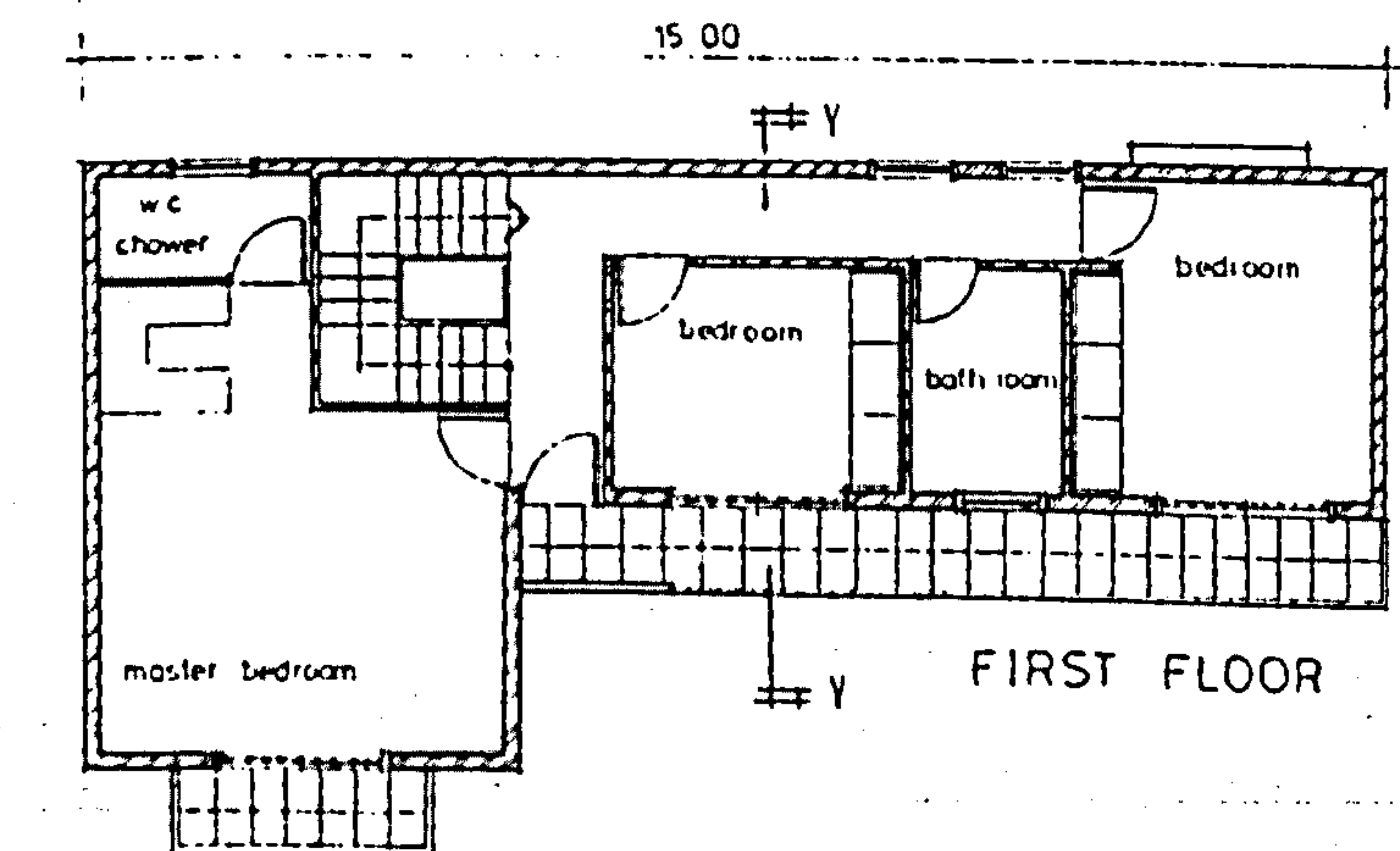
GROUND FLOOR



REAR ELEVATION



SECTION Y-Y



FIRST FLOOR

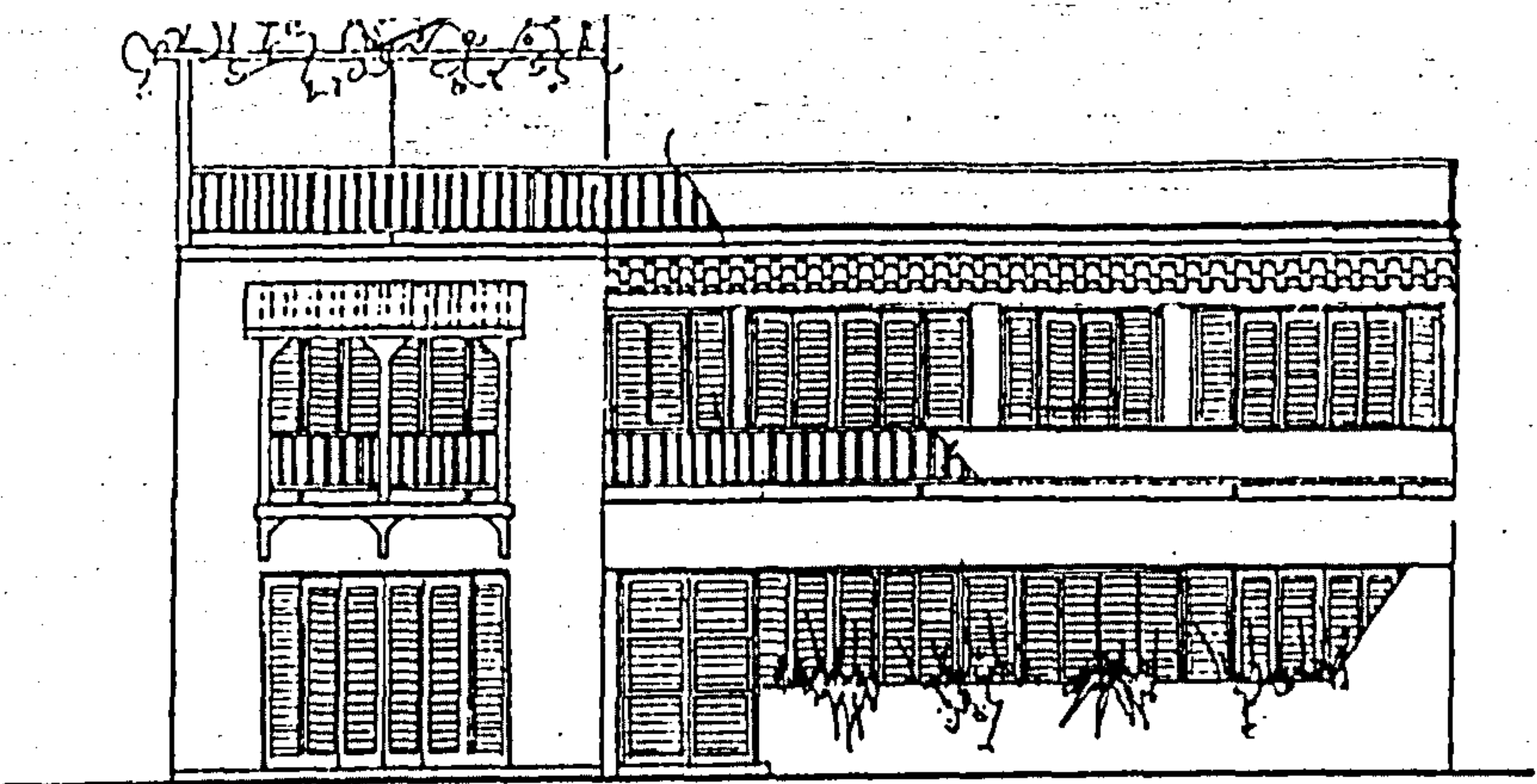


TEST NO: L2

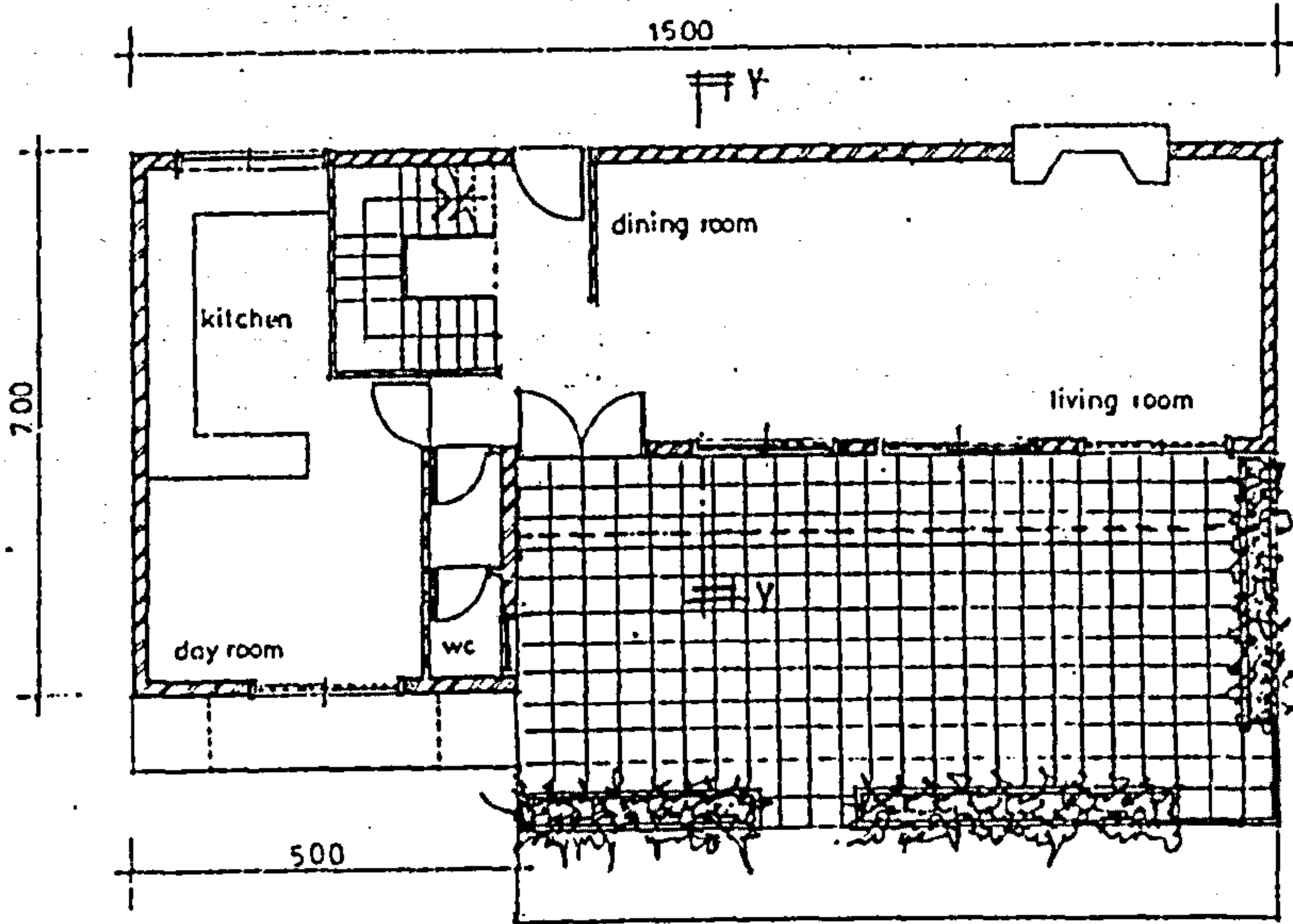
DESIGN PARAMETER: GLAZING  
STH Window area Increased by  
20m<sup>2</sup>

NRTH Window Area decreased  
by 1.75m<sup>2</sup>

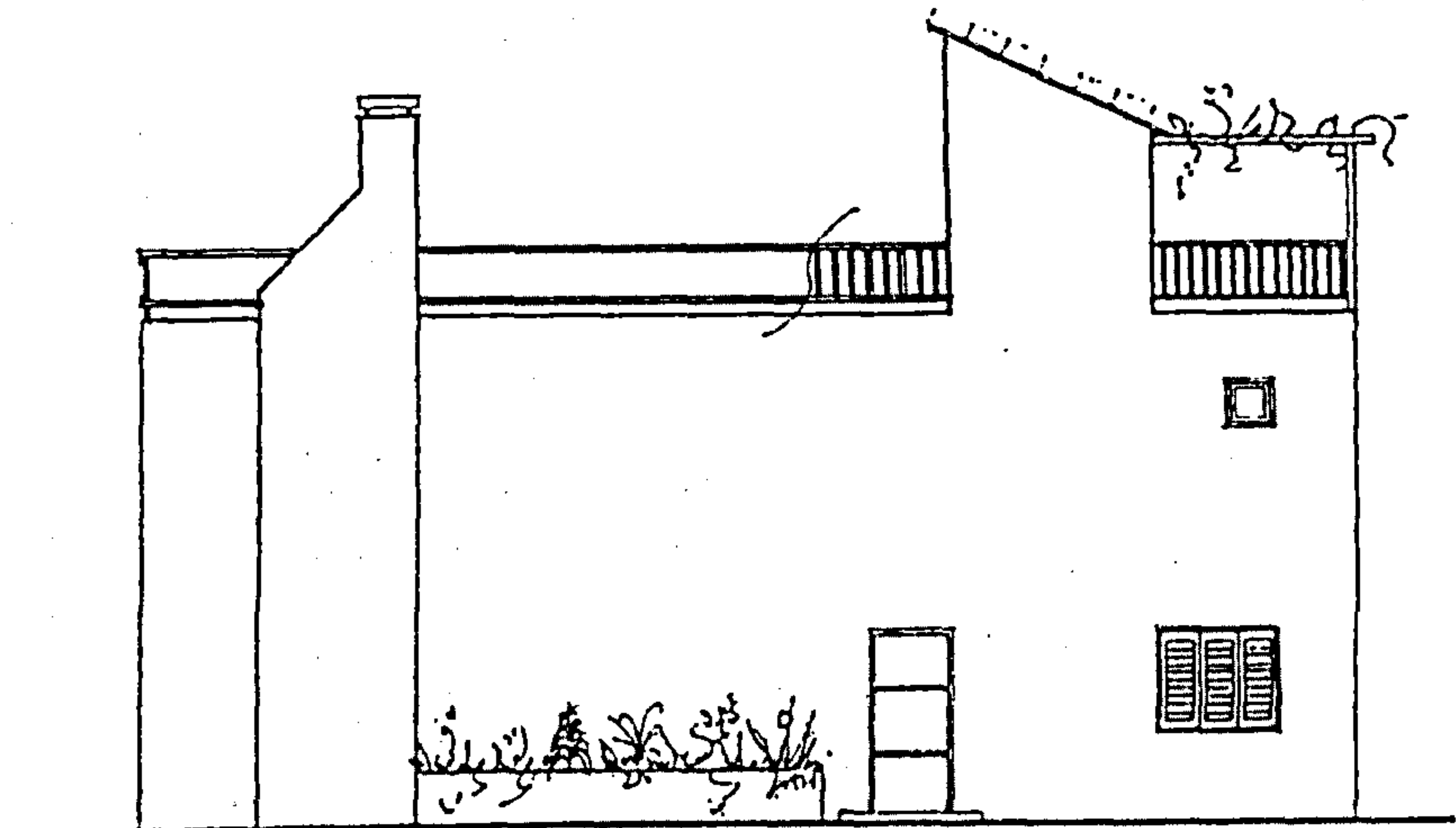
on L1



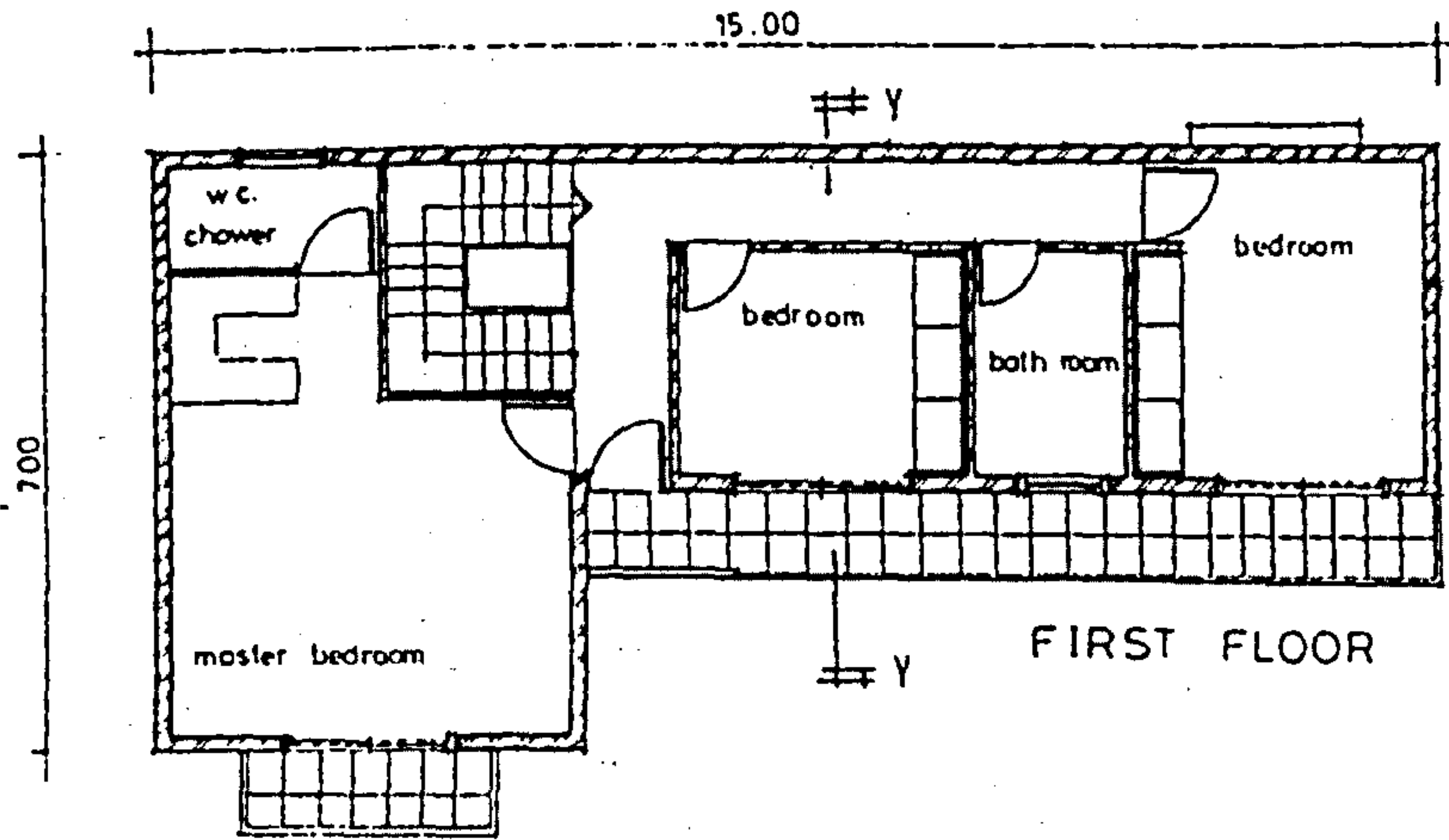
FRONT ELEVATION



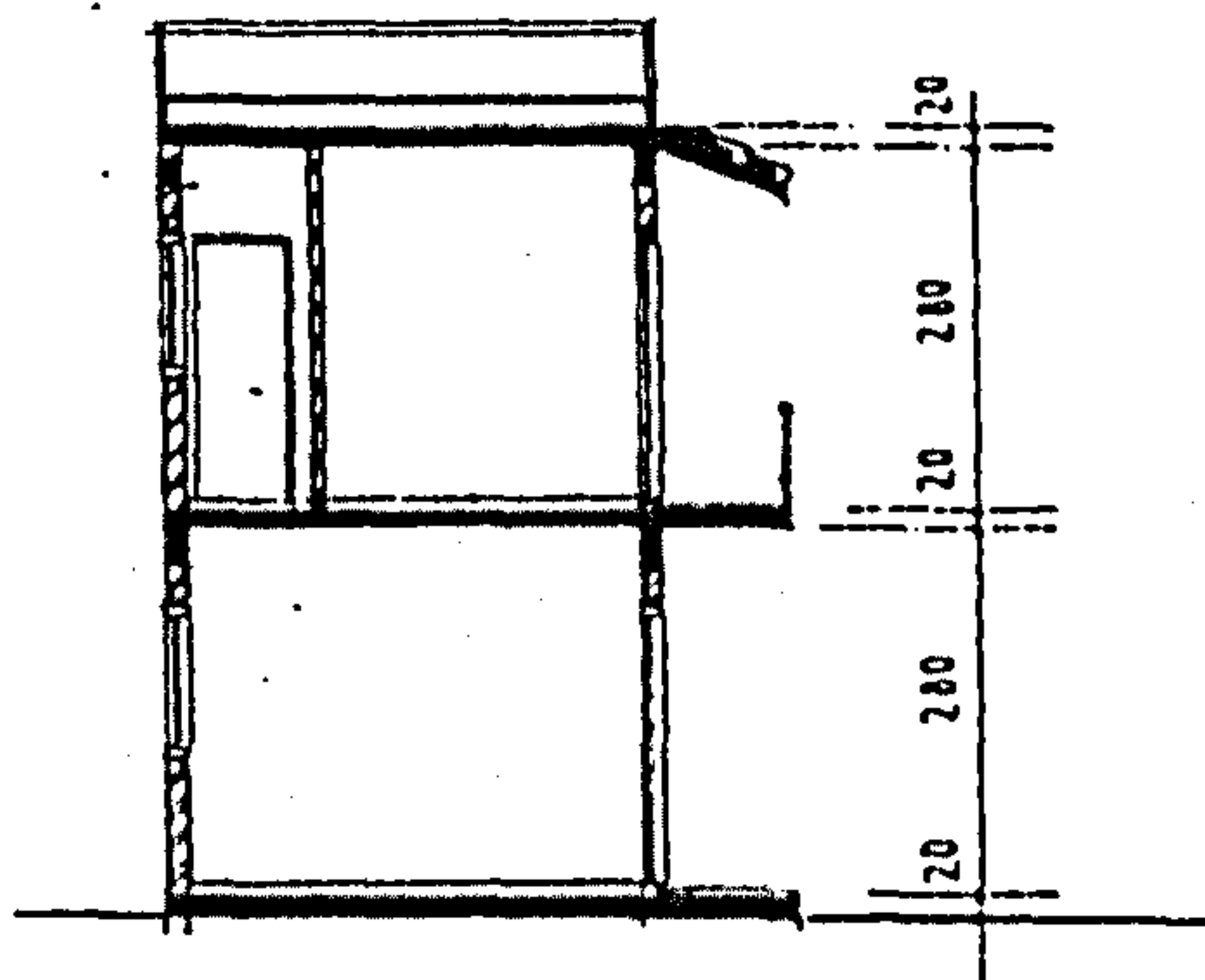
GROUND FLOOR



REAR ELEVATION



FIRST FLOOR



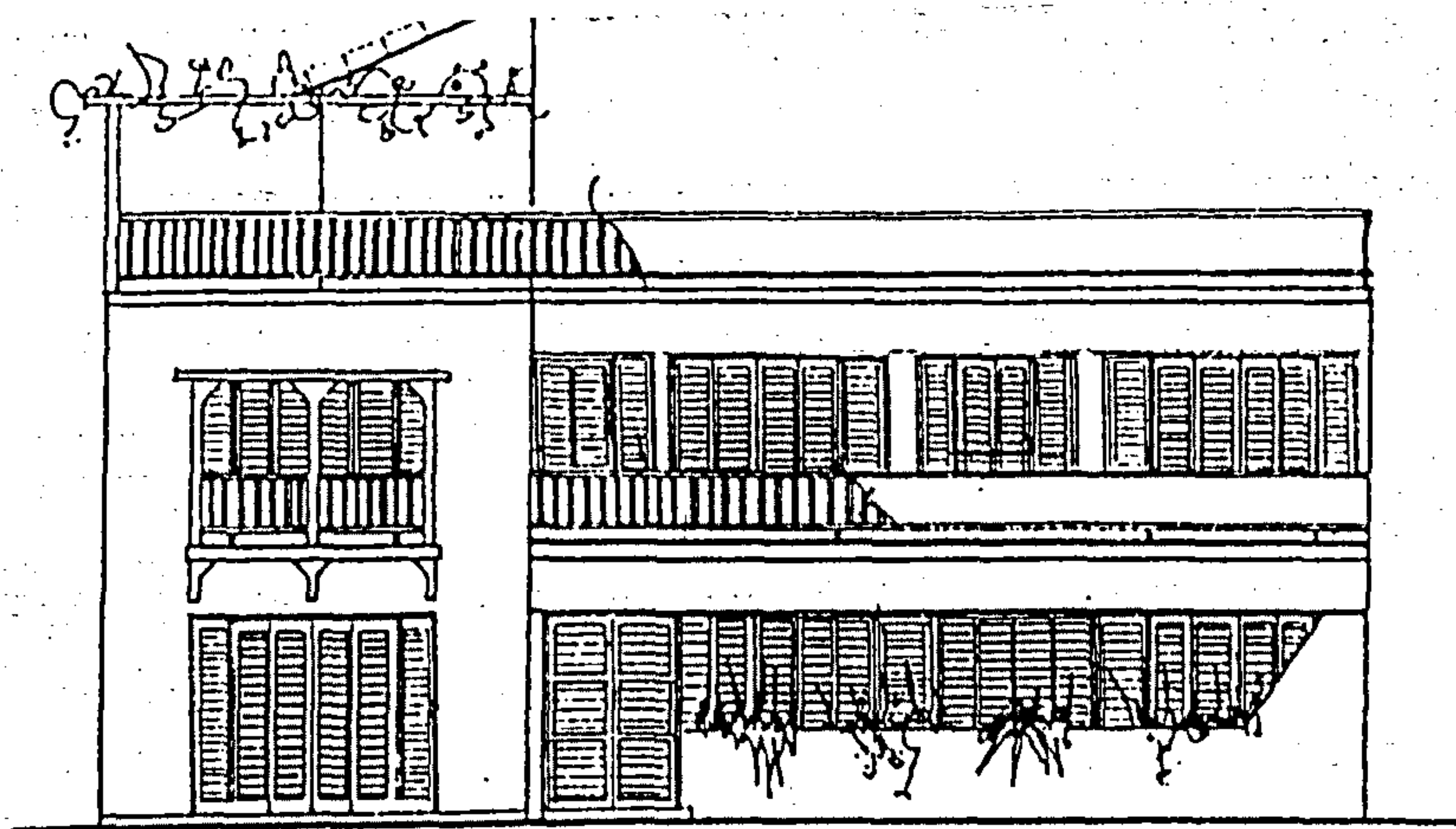
SECTION Y-Y



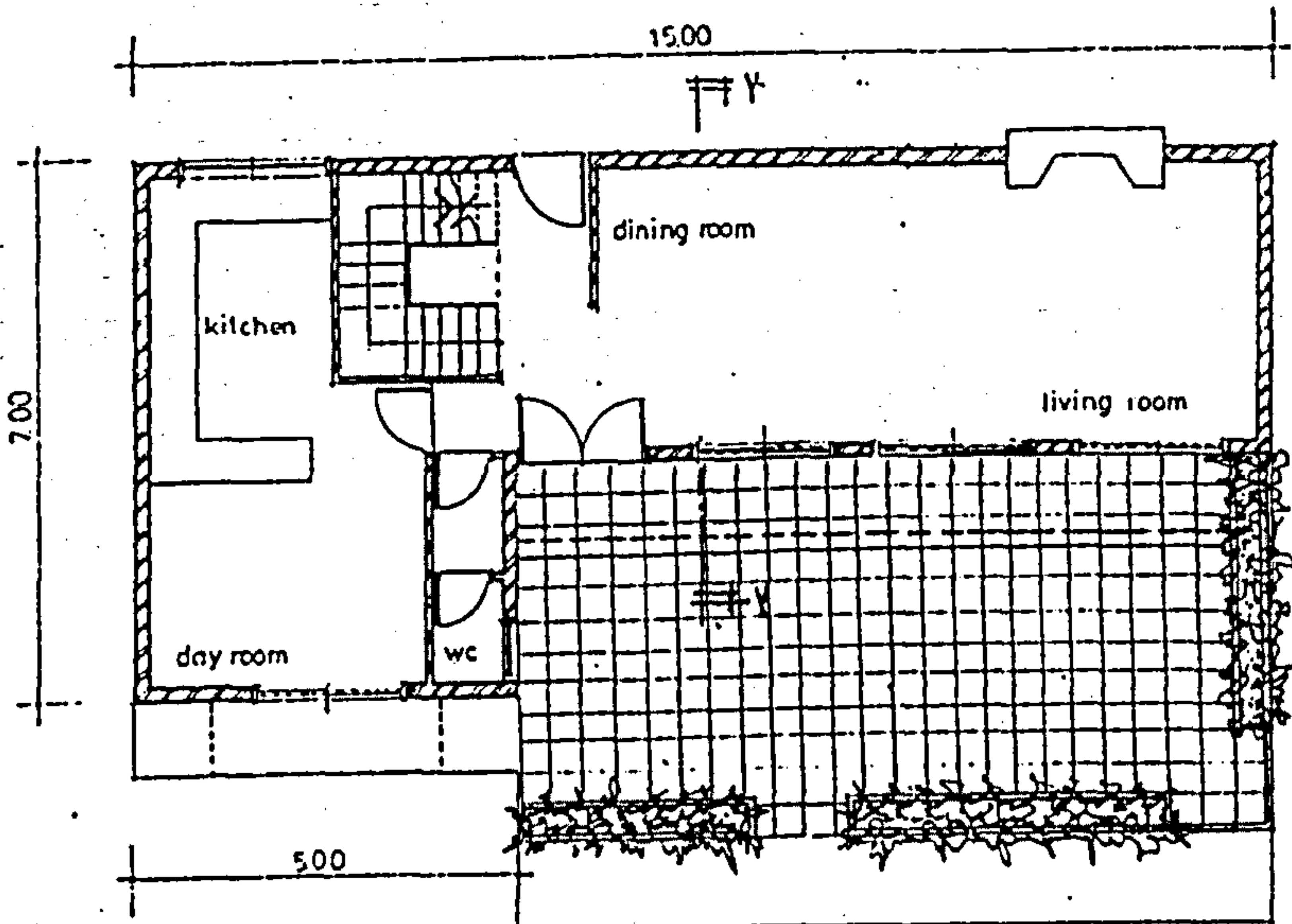
TEST NO: L3

DESIGN PARAMETER: GLAZING-SHADE

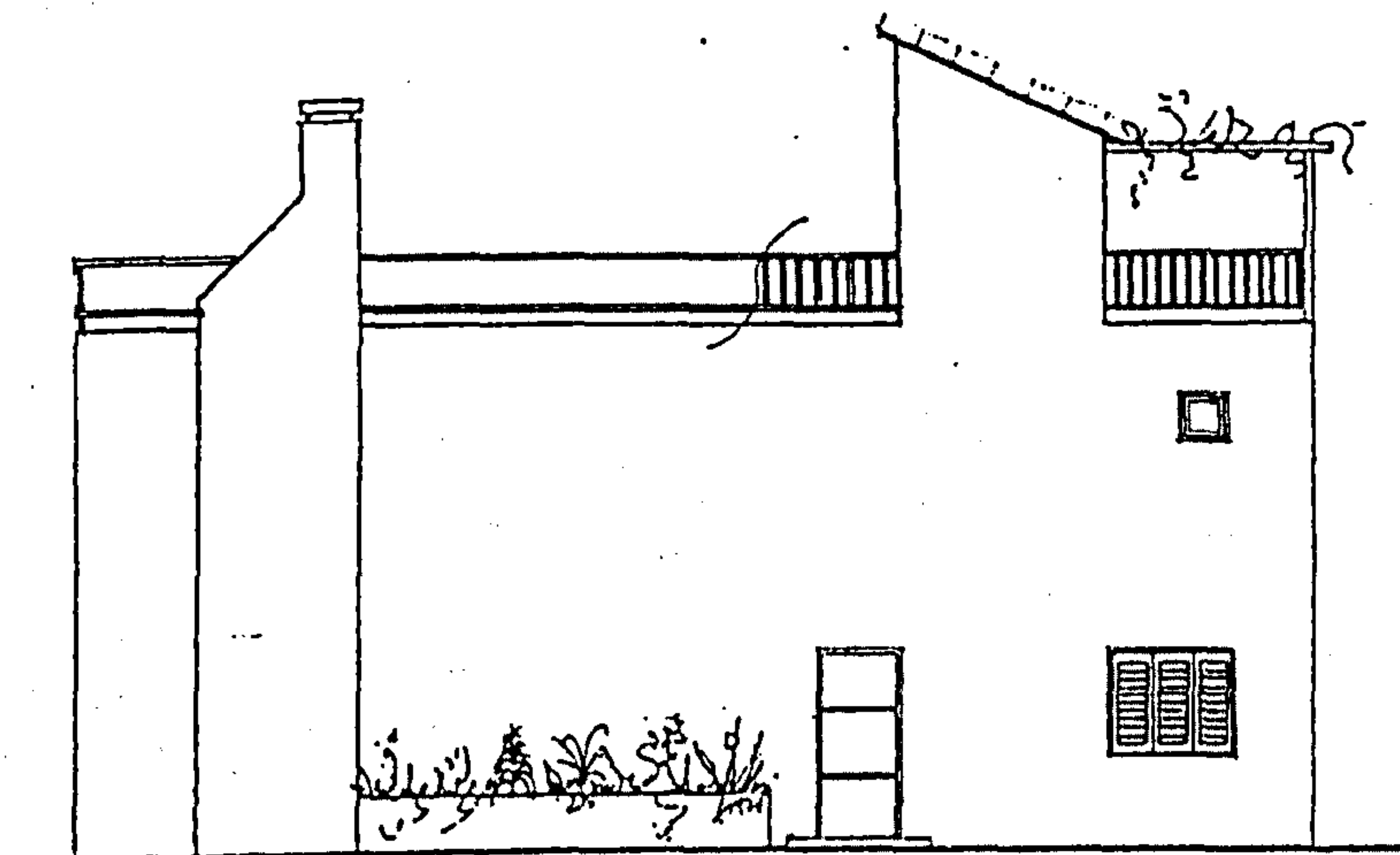
Overhang Raised by 50cm on L2



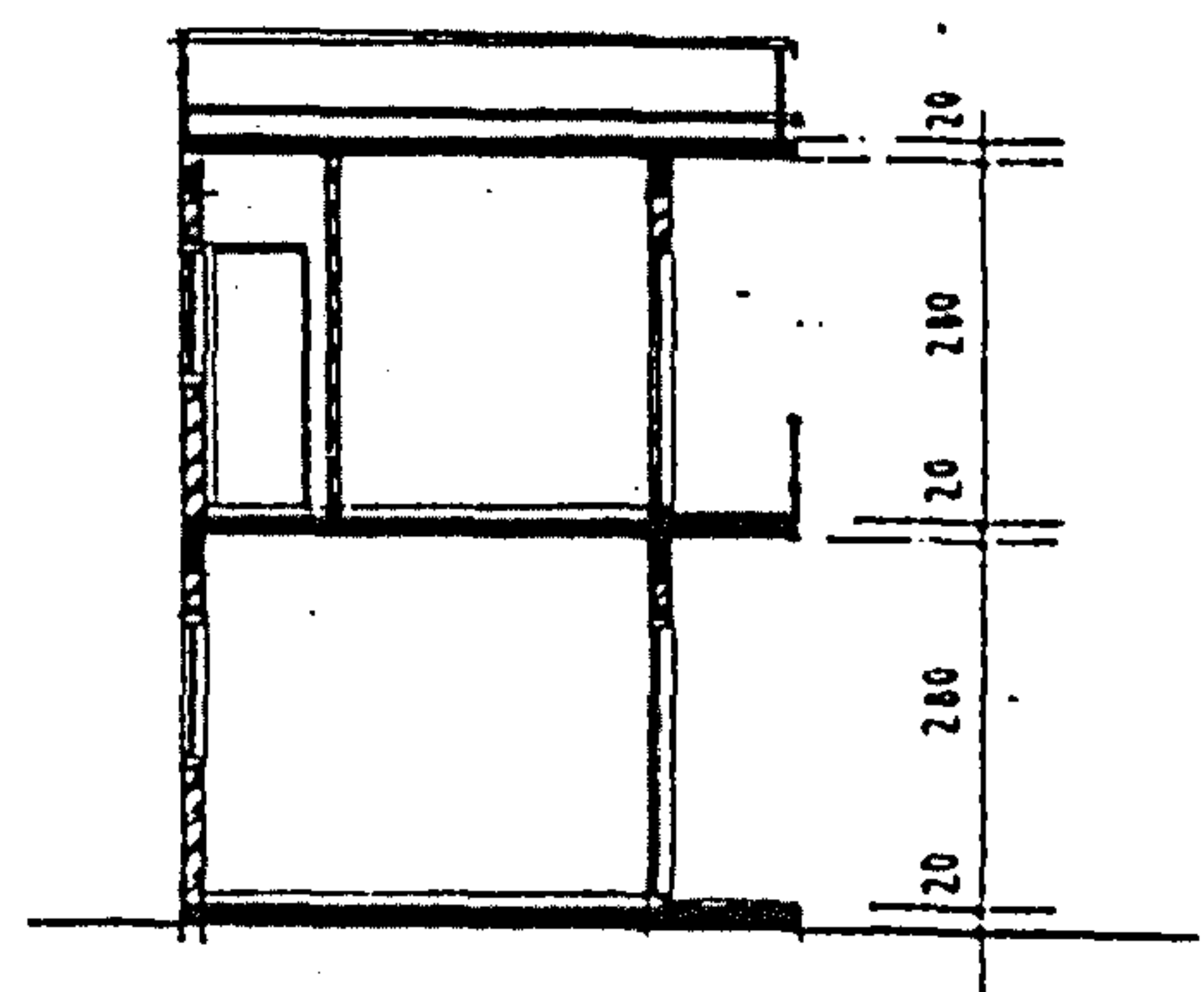
FRONT ELEVATION



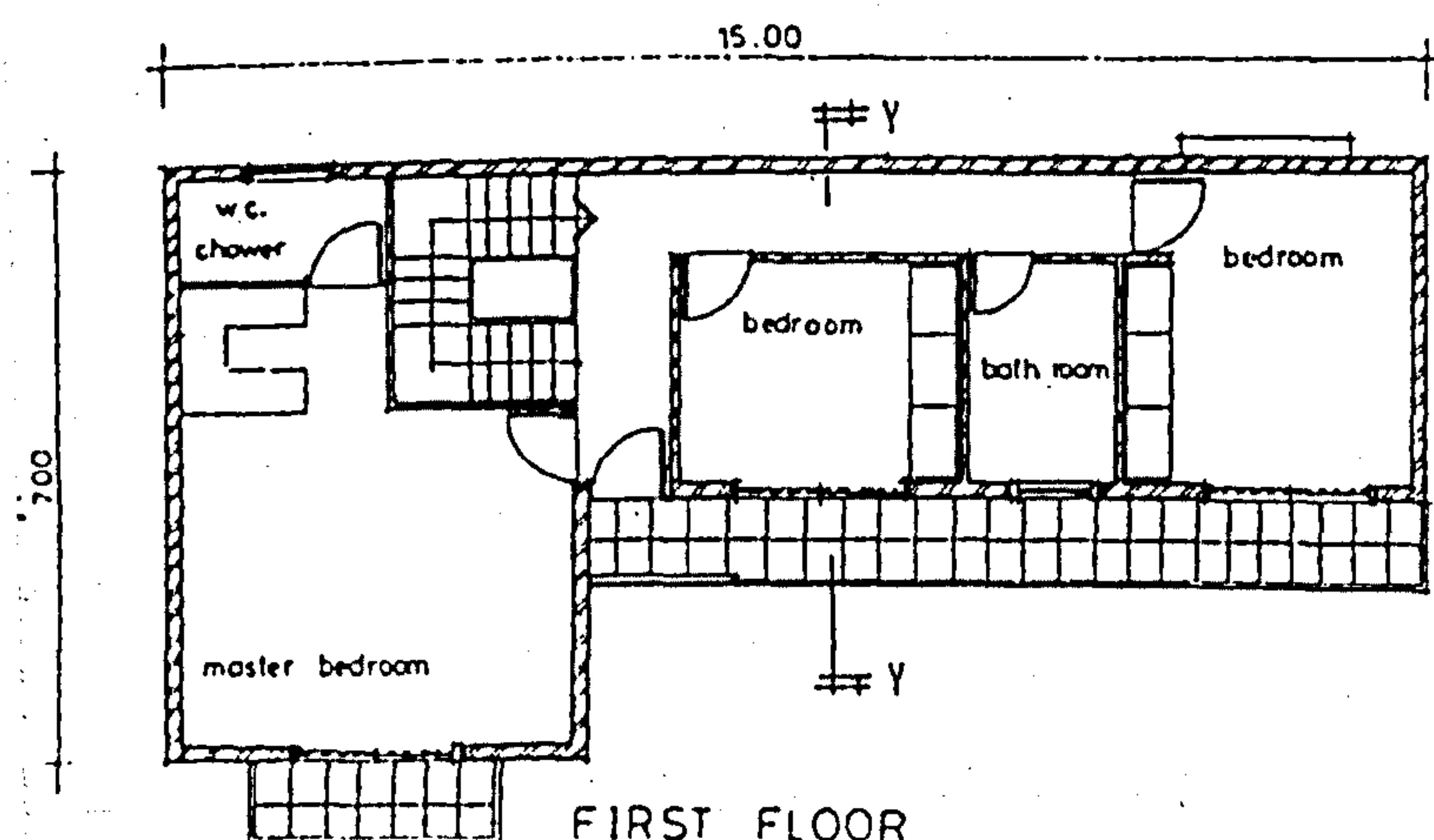
GROUND FLOOR



REAR ELEVATION



SECTION Y-Y

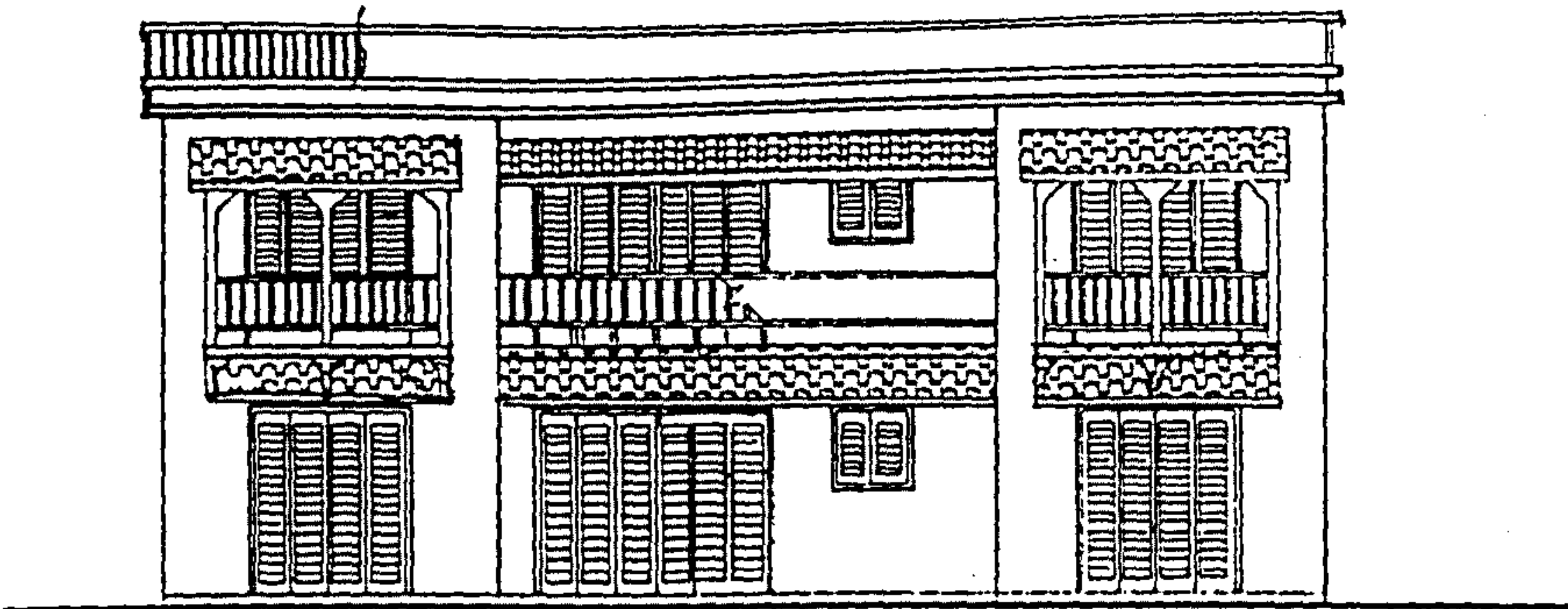


FIRST FLOOR

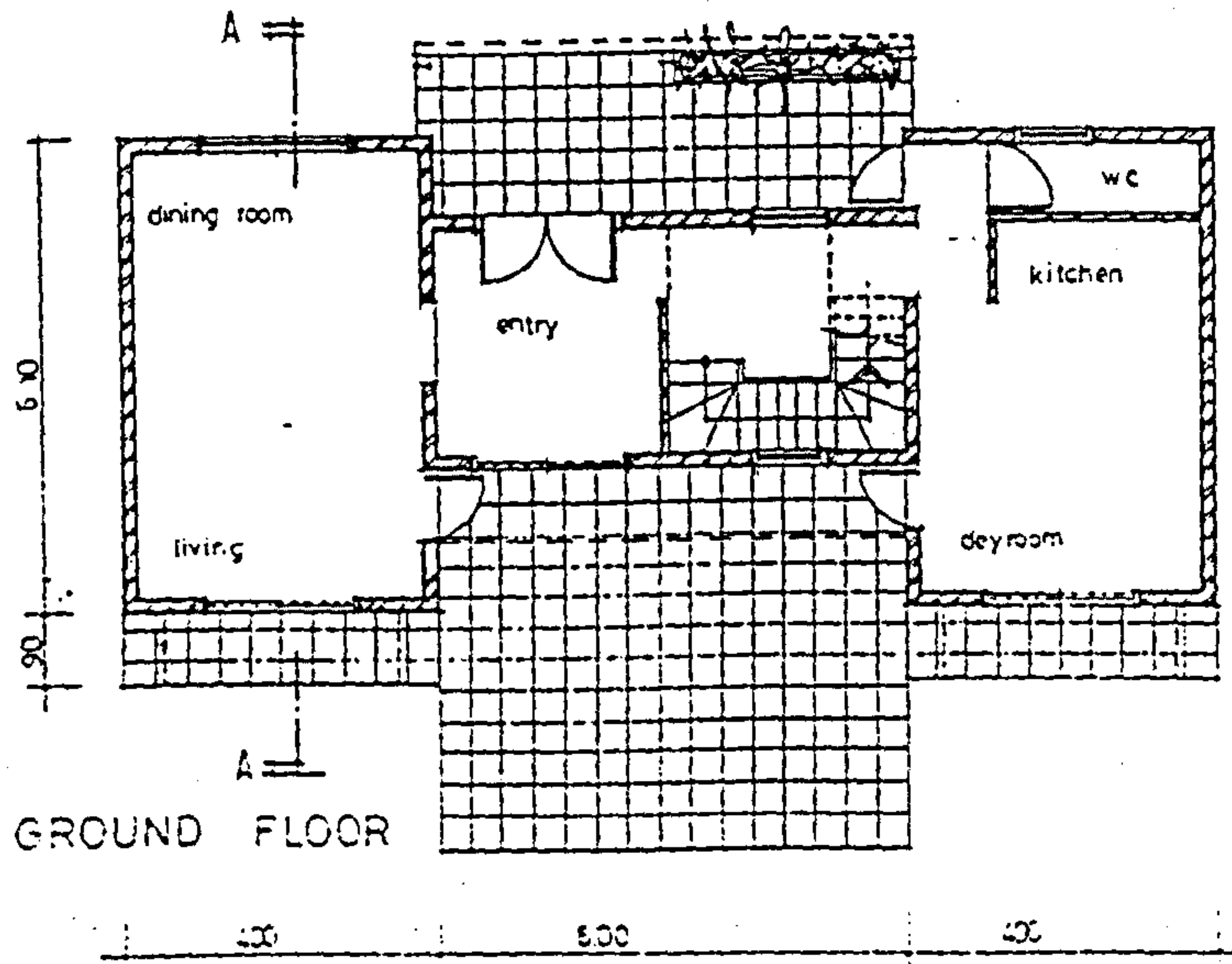


TEST NO: P1

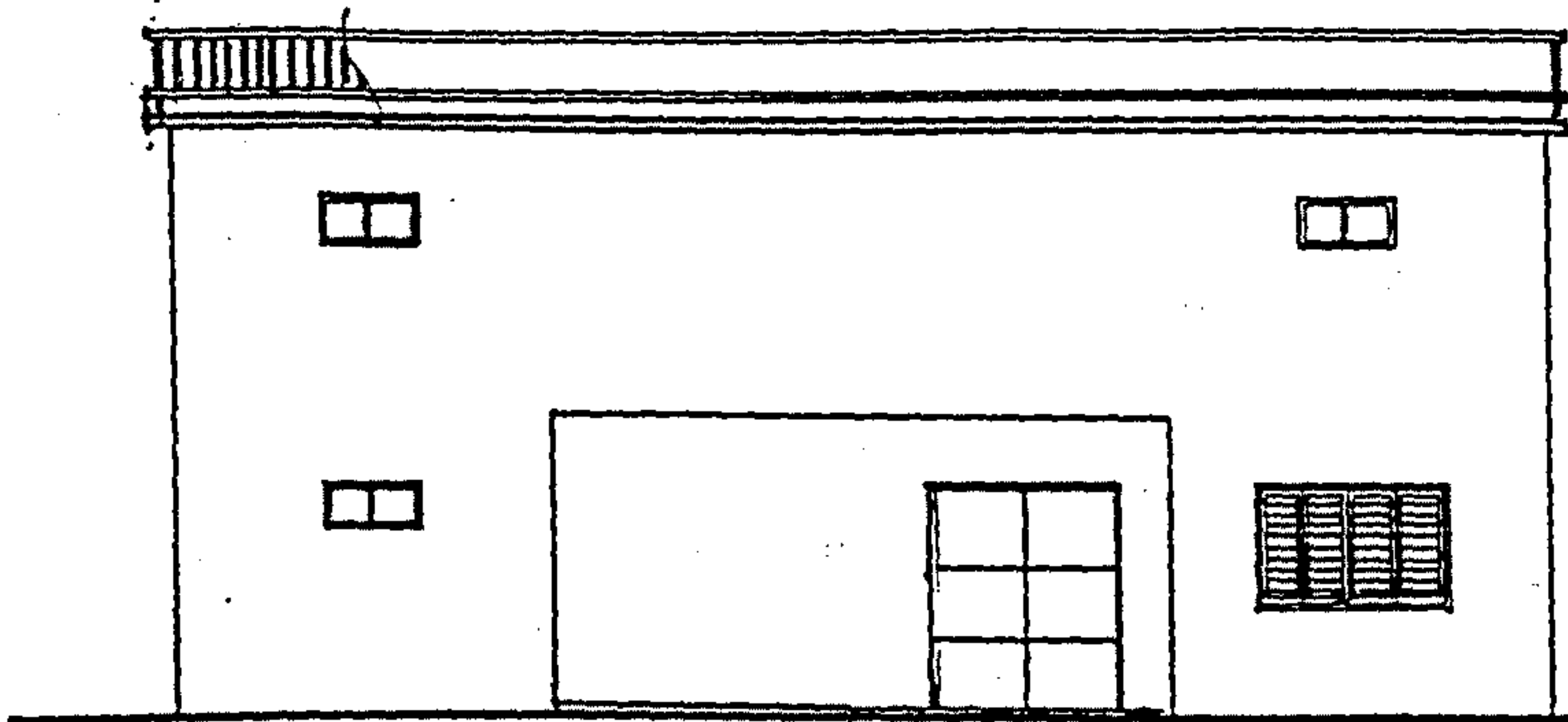
DESIGN PARAMETER: SHAPE -II



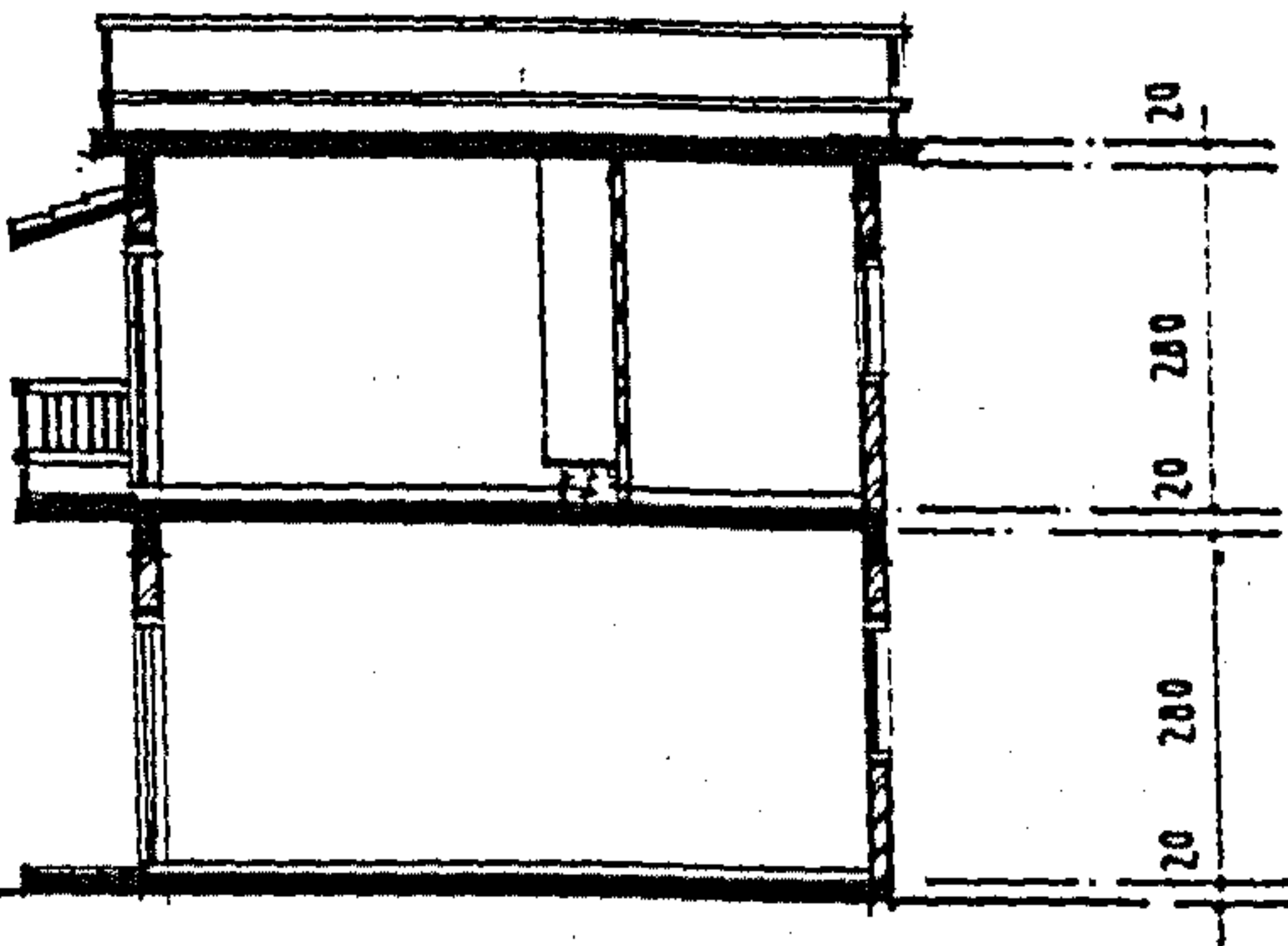
FRONT ELEVATION



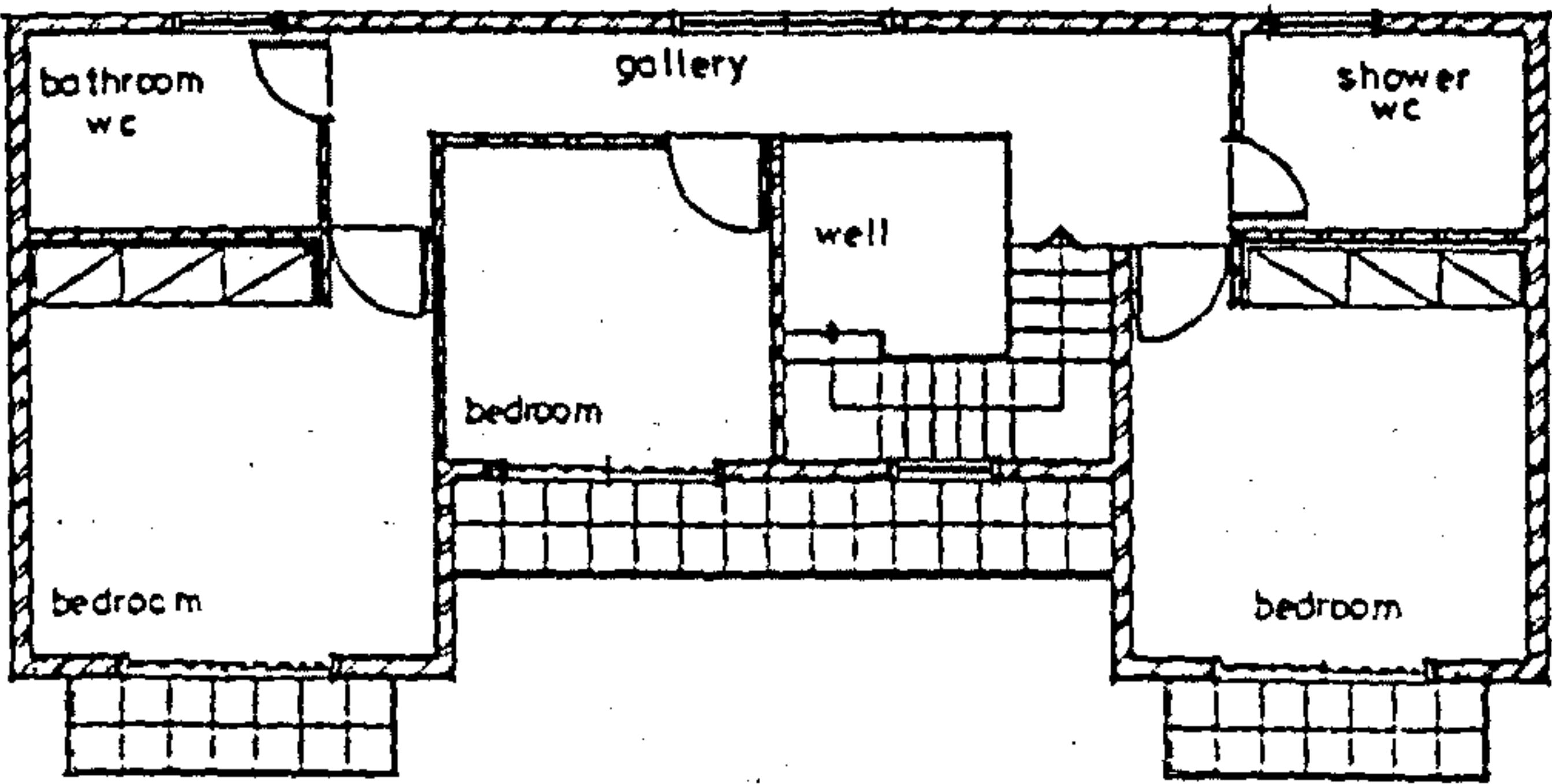
GROUND FLOOR



REAR ELEVATION



SECTION A-A



FIRST FLOOR

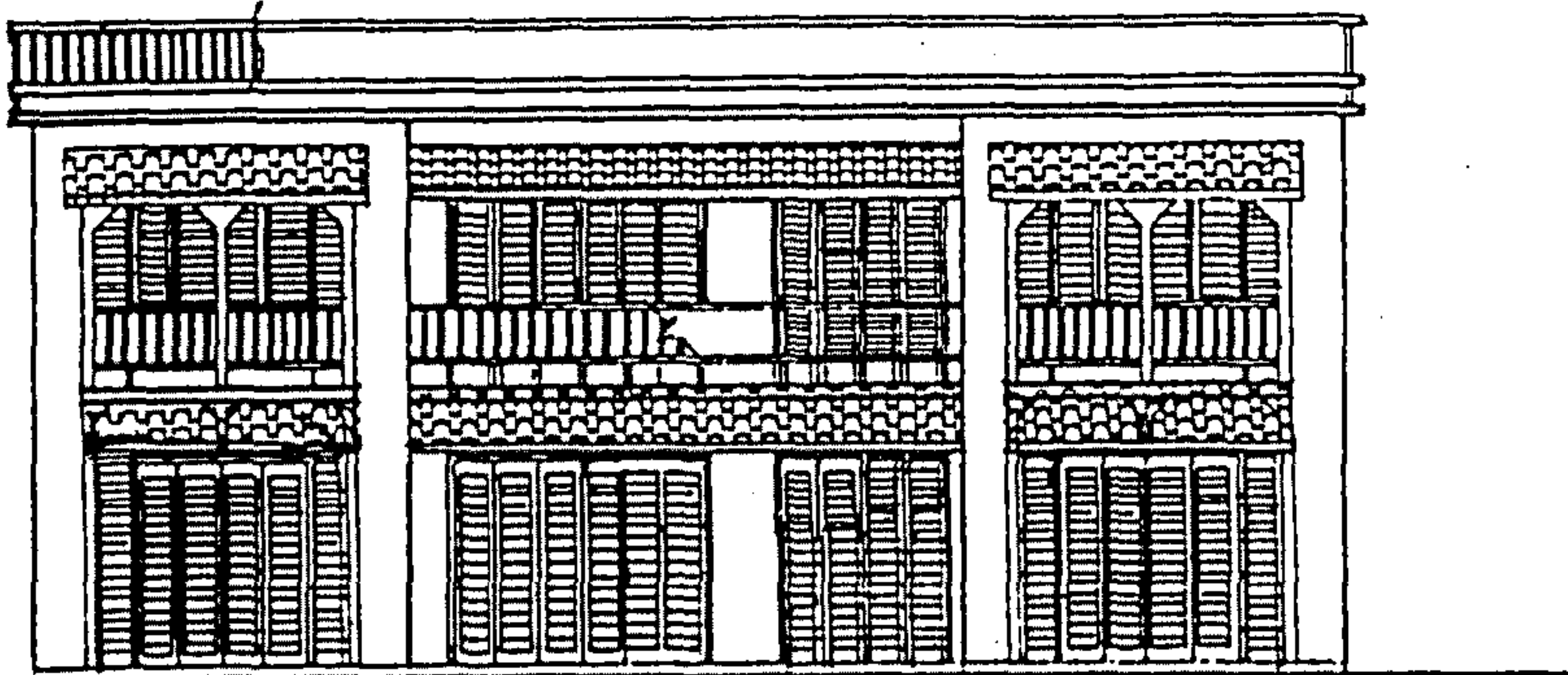


TEST NO: P2

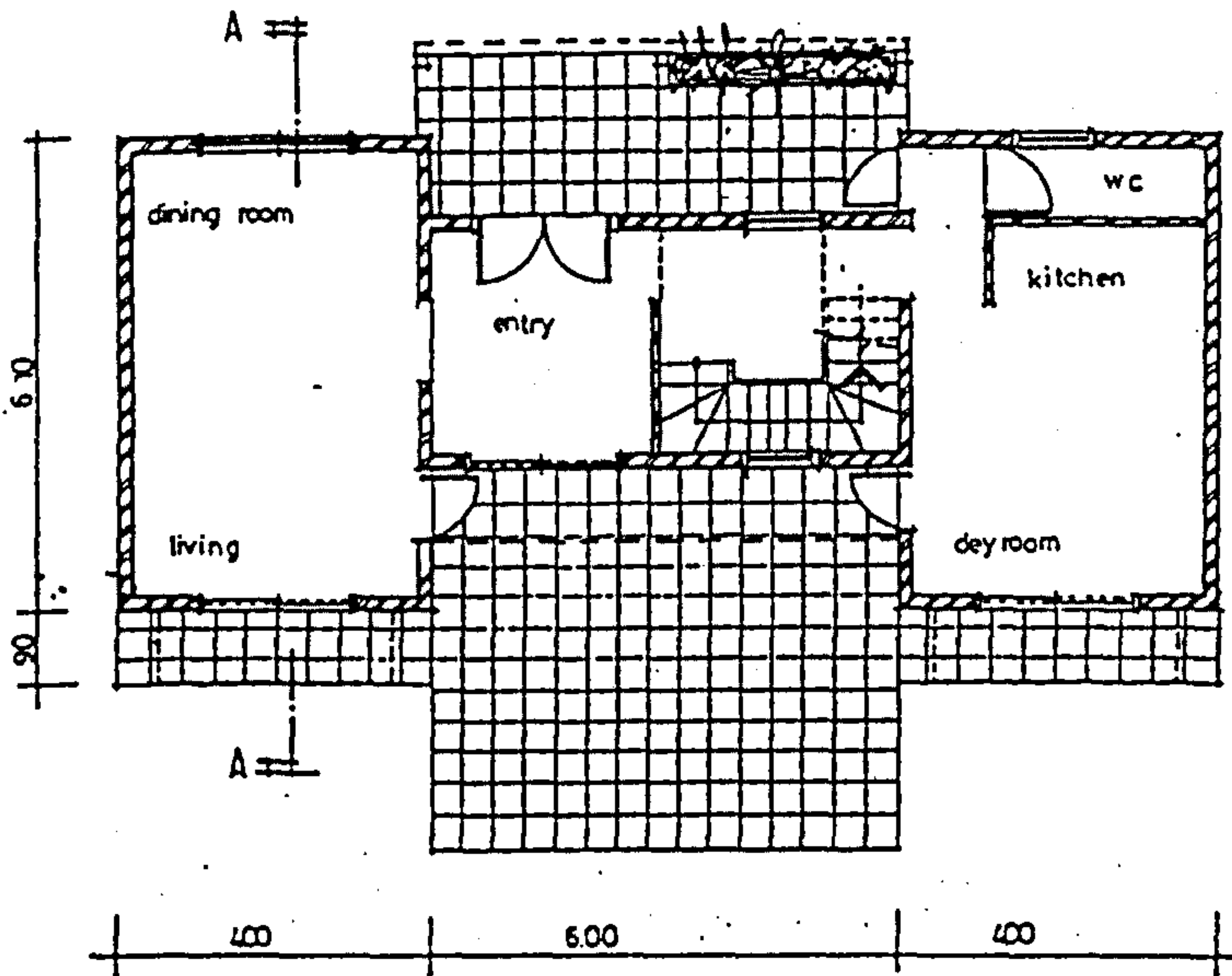
DESIGN PARAMETER: GLAZING

STH Window Area Increased  
by 19m<sup>2</sup>

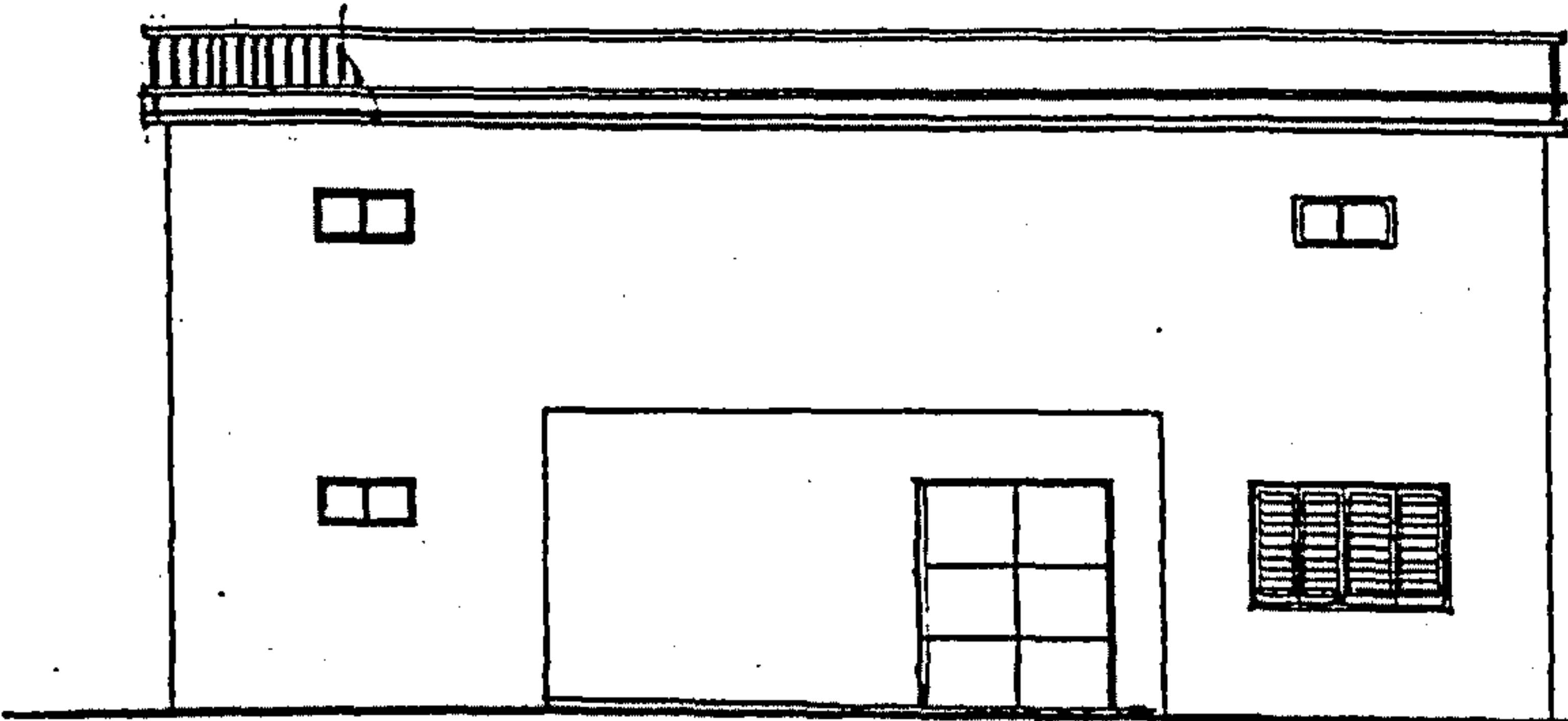
NRTH Window Area Decreased  
by 15m<sup>2</sup> on P1



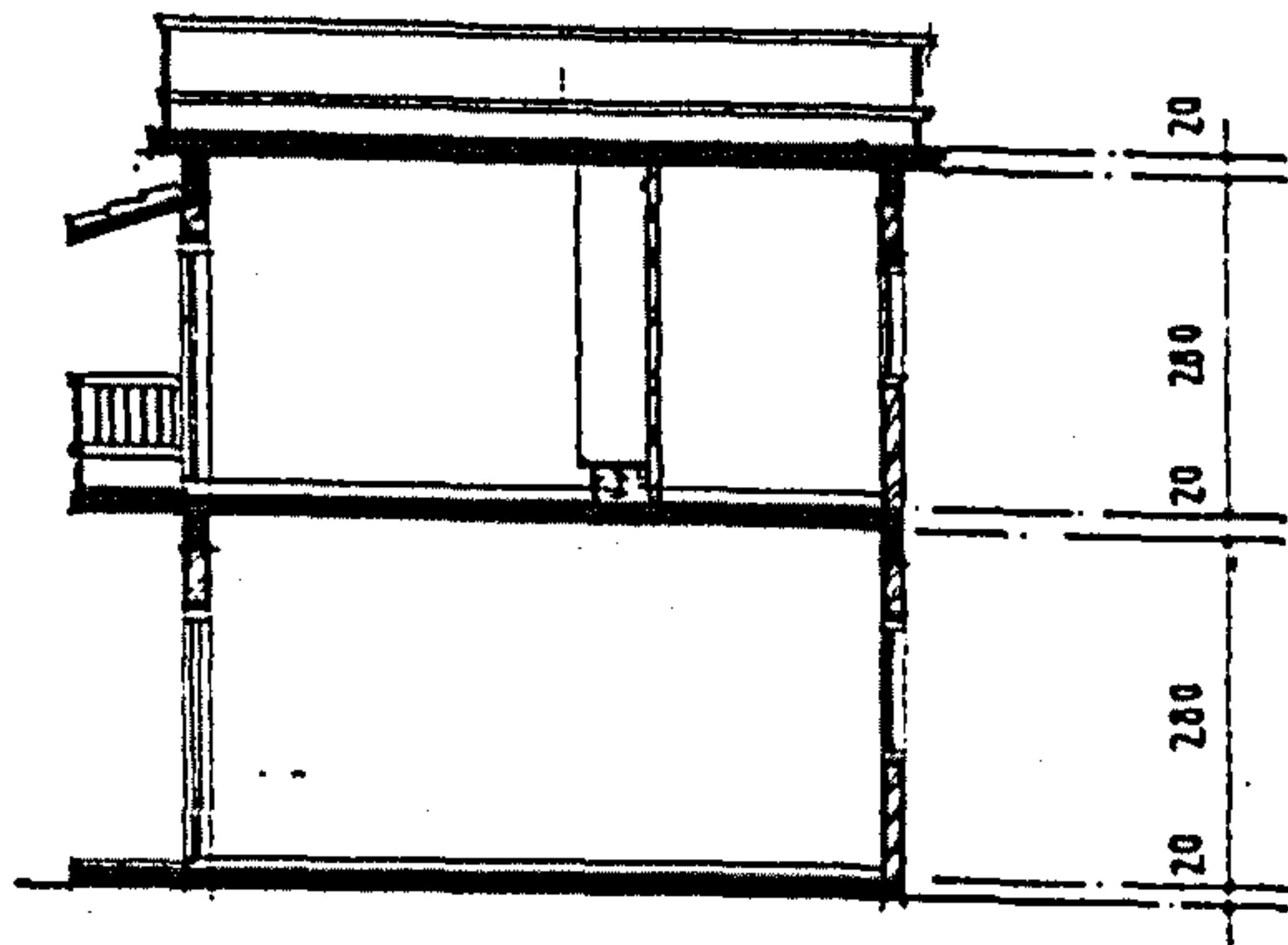
FRONT ELEVATION



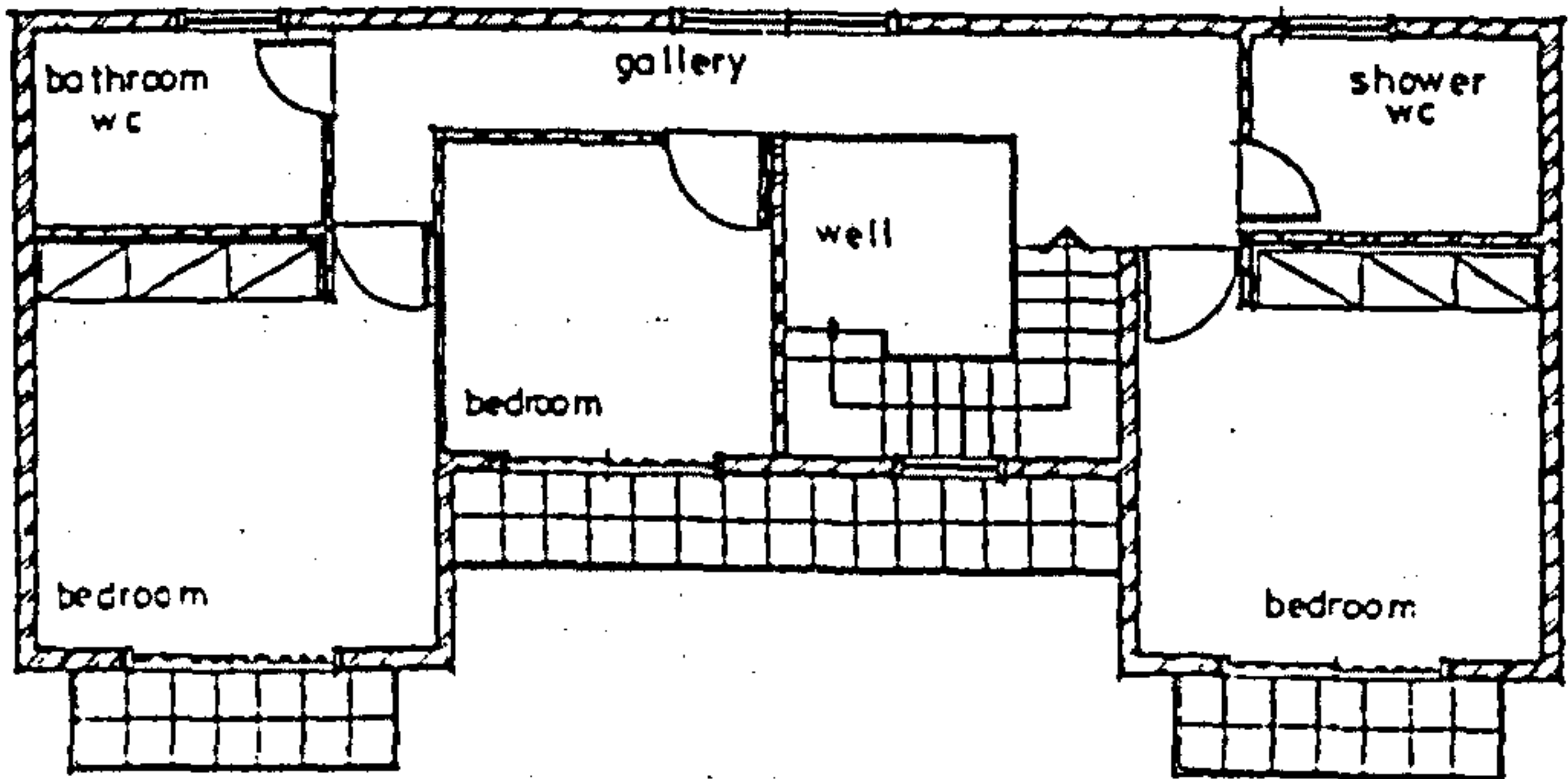
GROUND FLOOR



REAR ELEVATION



SECTION A-A



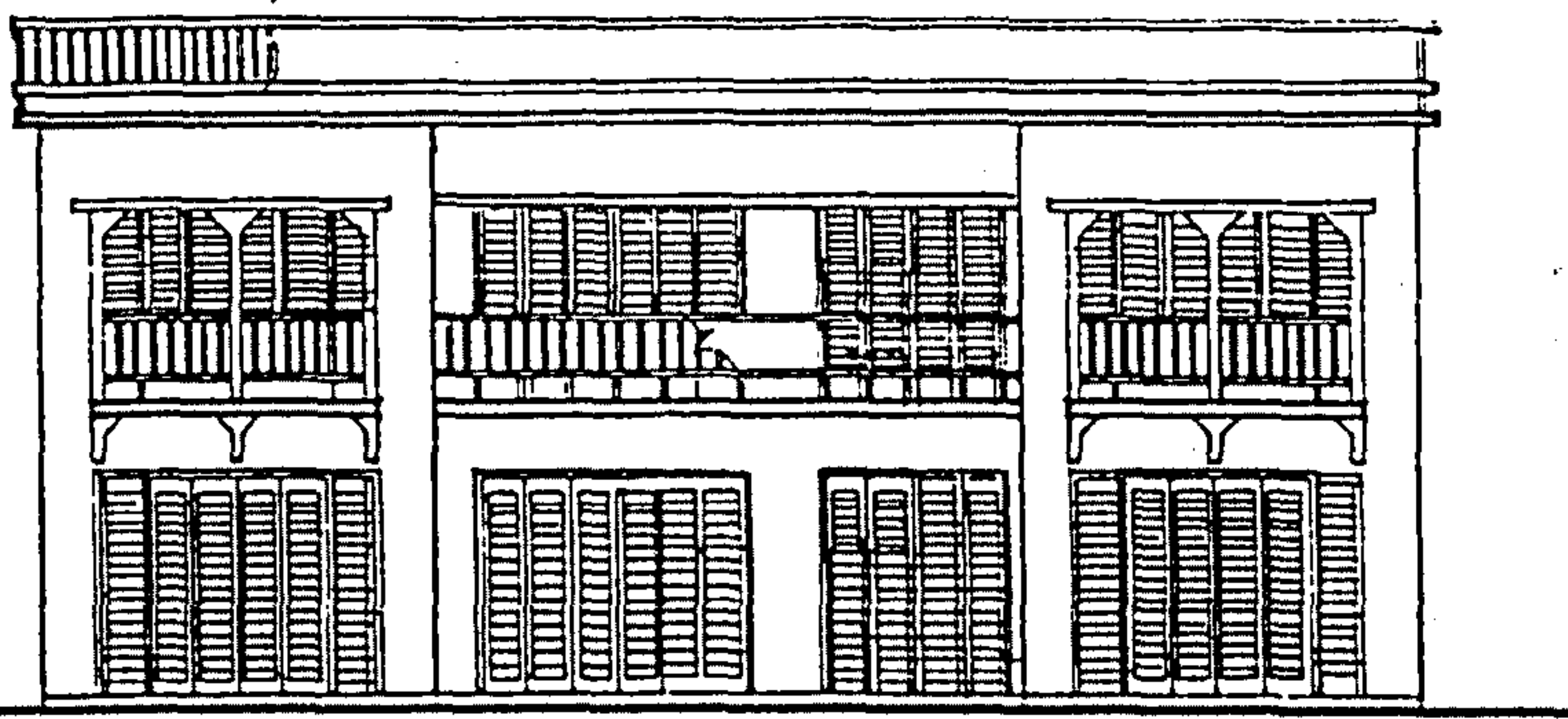
FIRST FLOOR



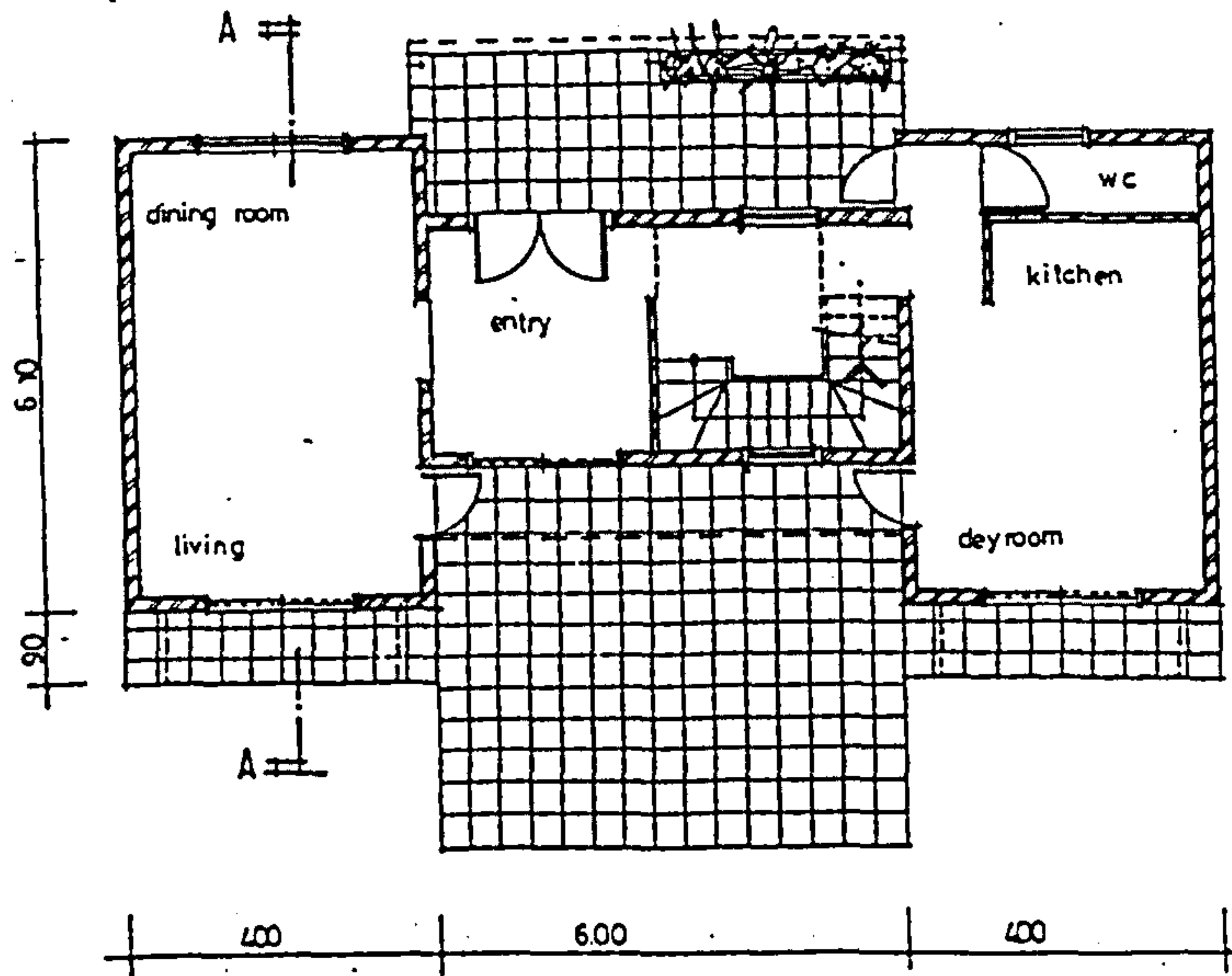
TEST NO:P3

DESIGN PARAMETER:GLAZING  
(shade)

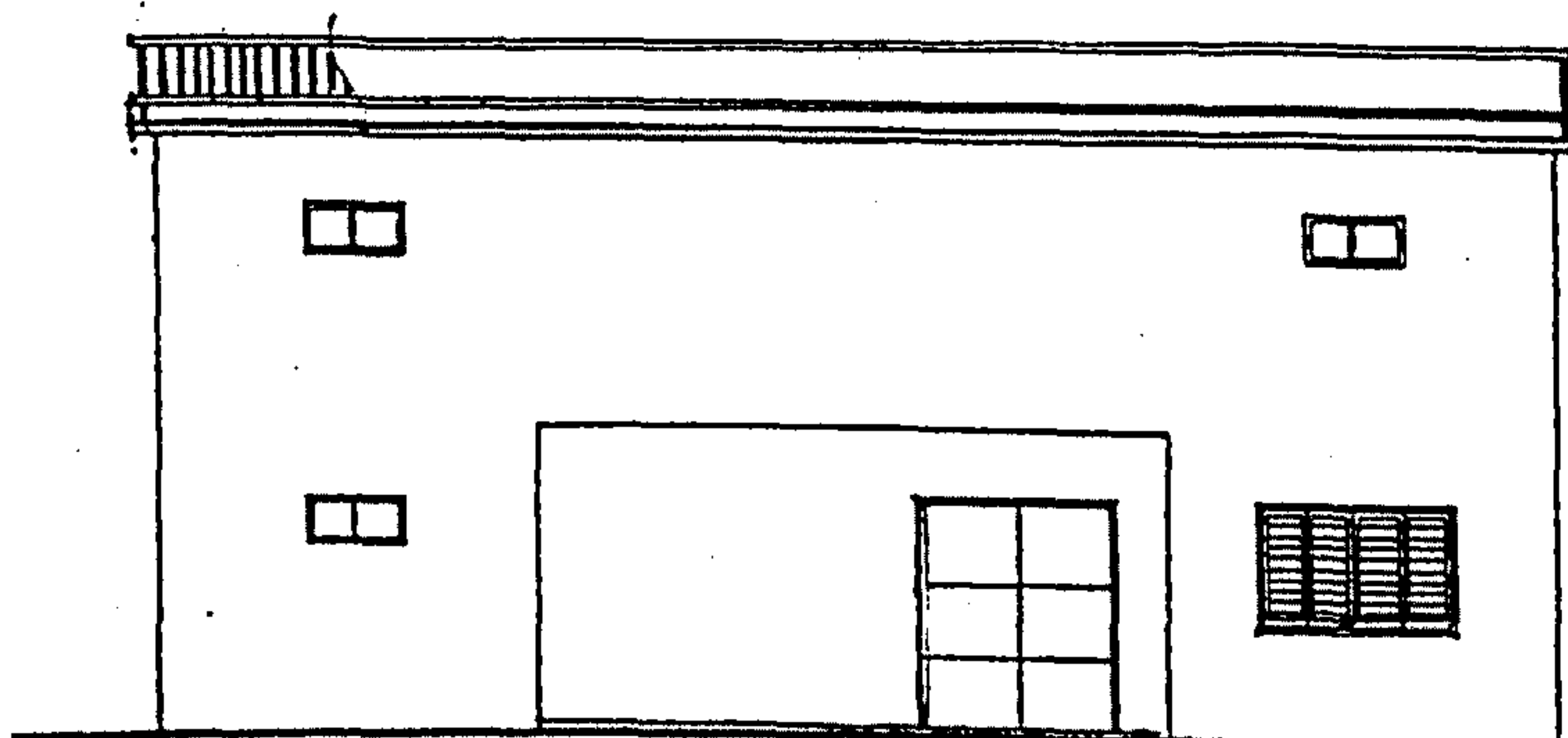
Overhang Raised by 50cm on  
P2



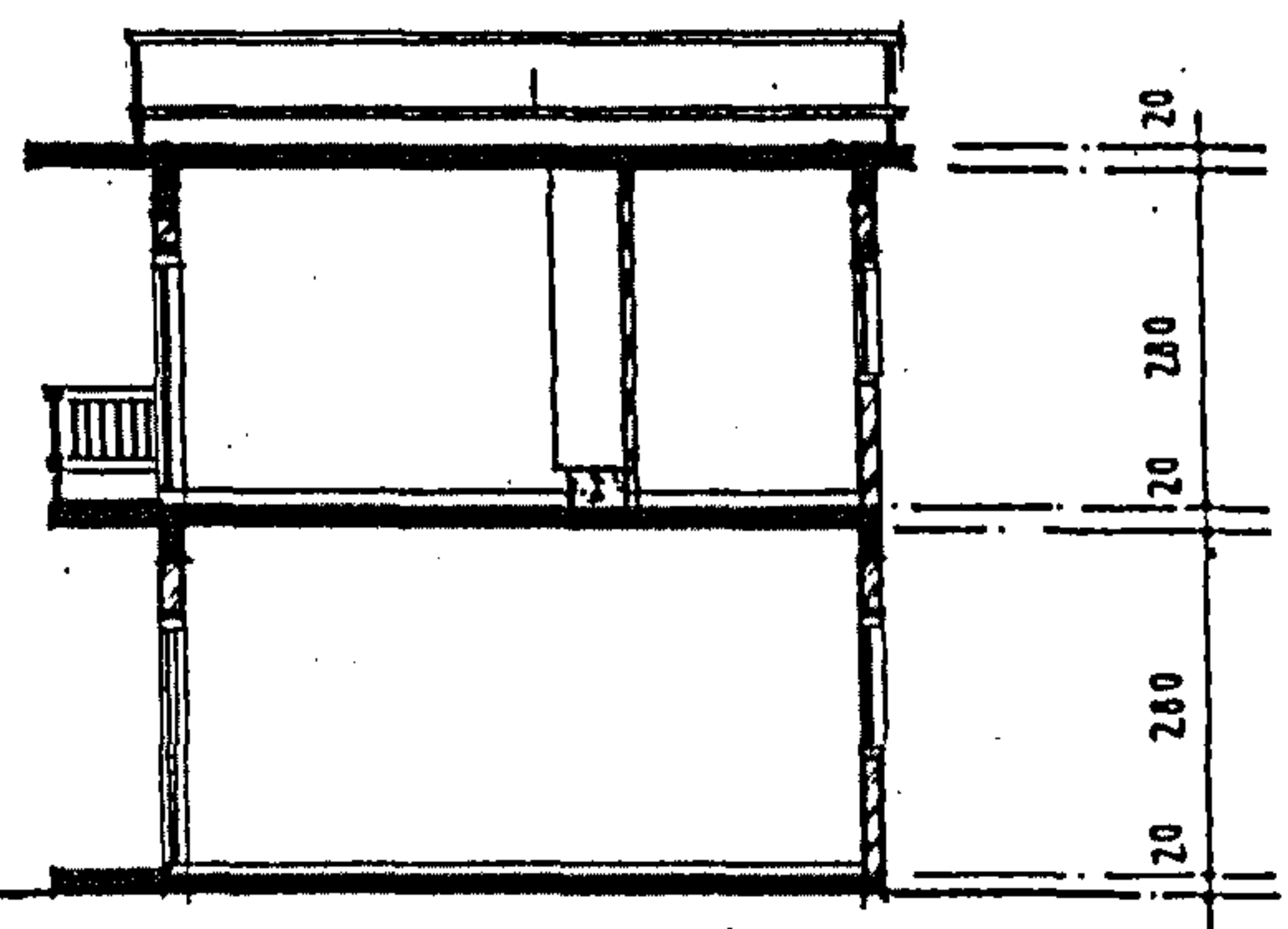
FRONT ELEVATION



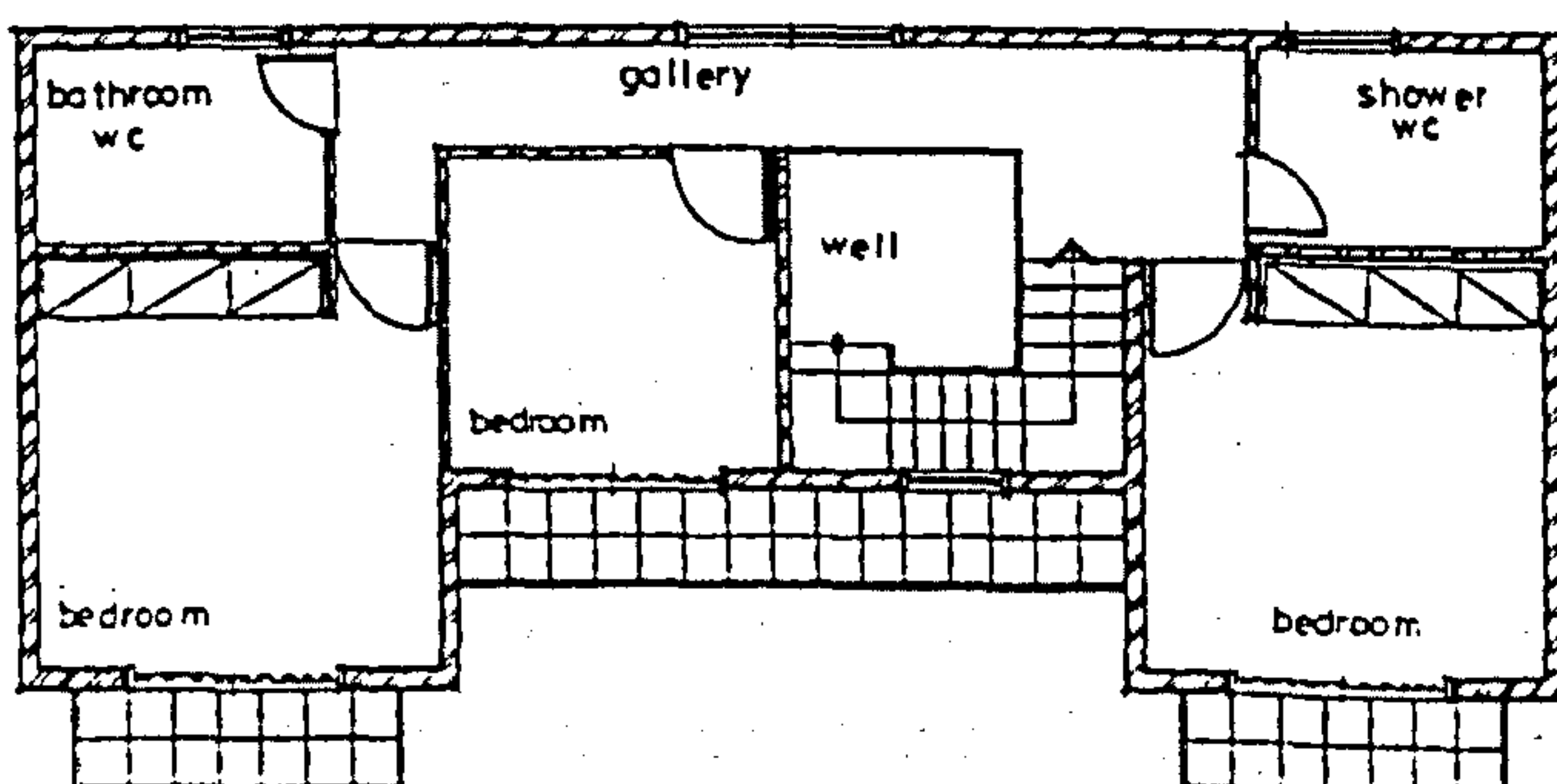
GROUND FLOOR



REAR ELEVATION



SECTION A-A

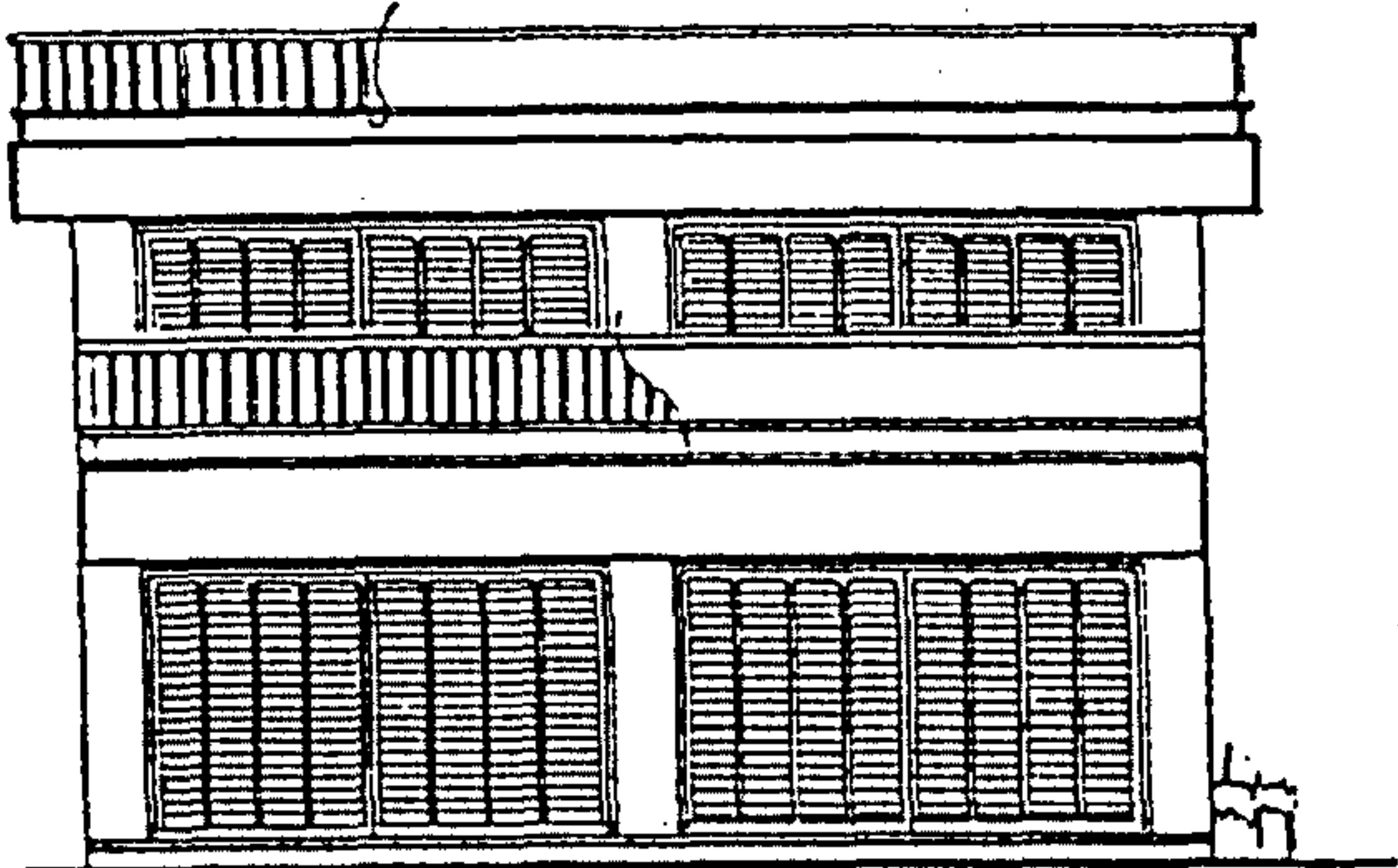


FIRST FLOOR

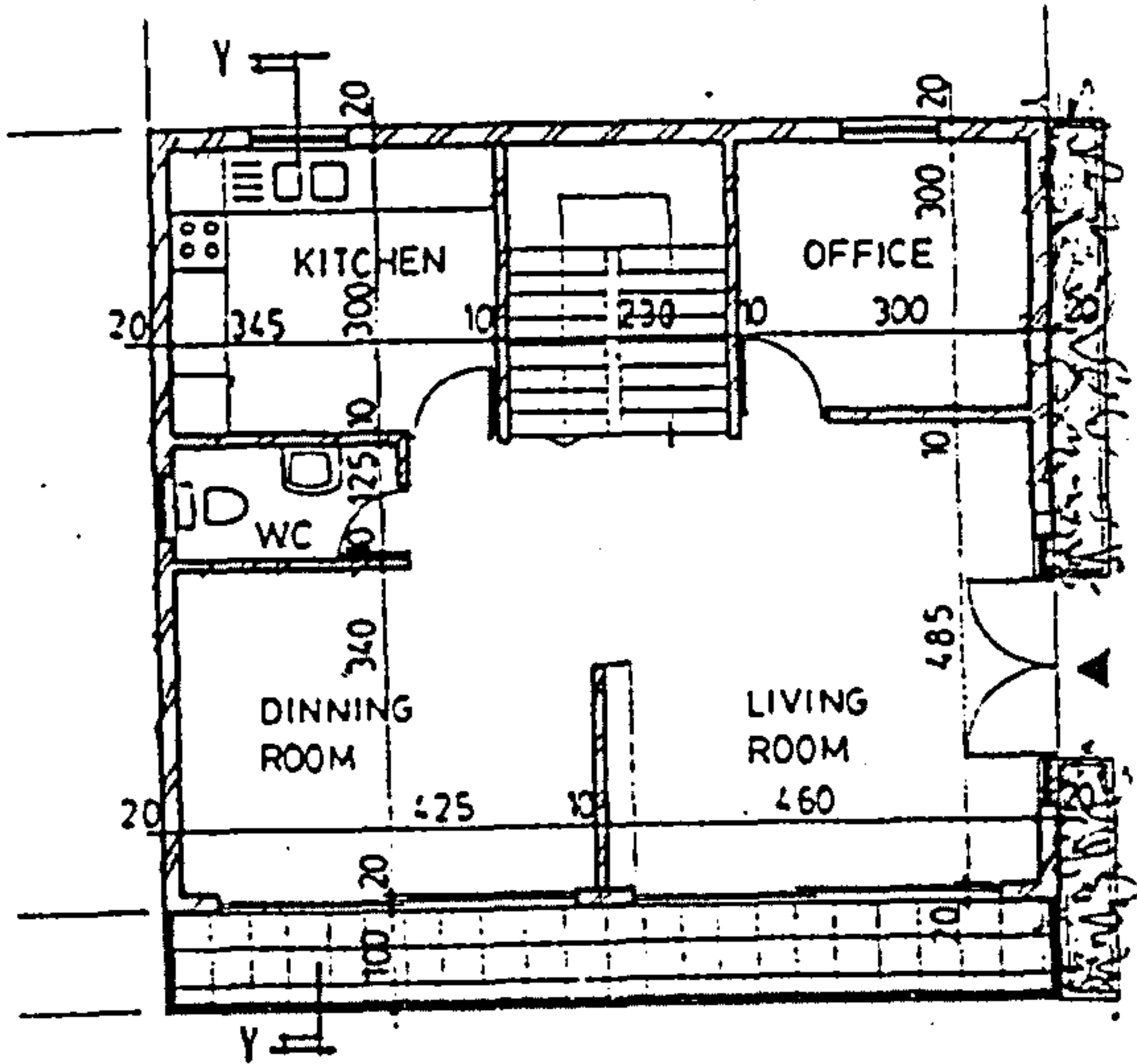


TEST NO: S1

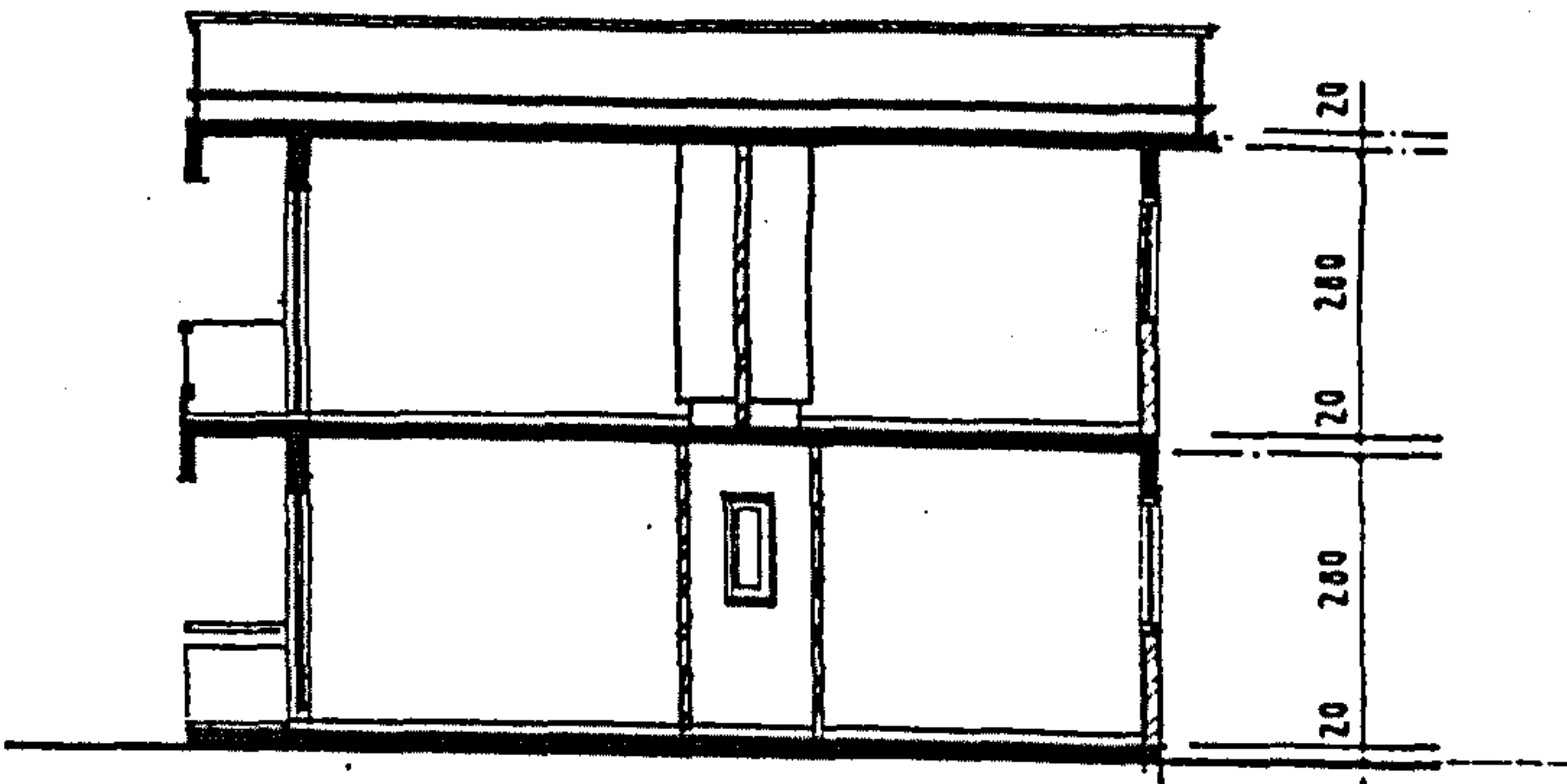
DESIGN PARAMETER: SHAPE-SQUARE



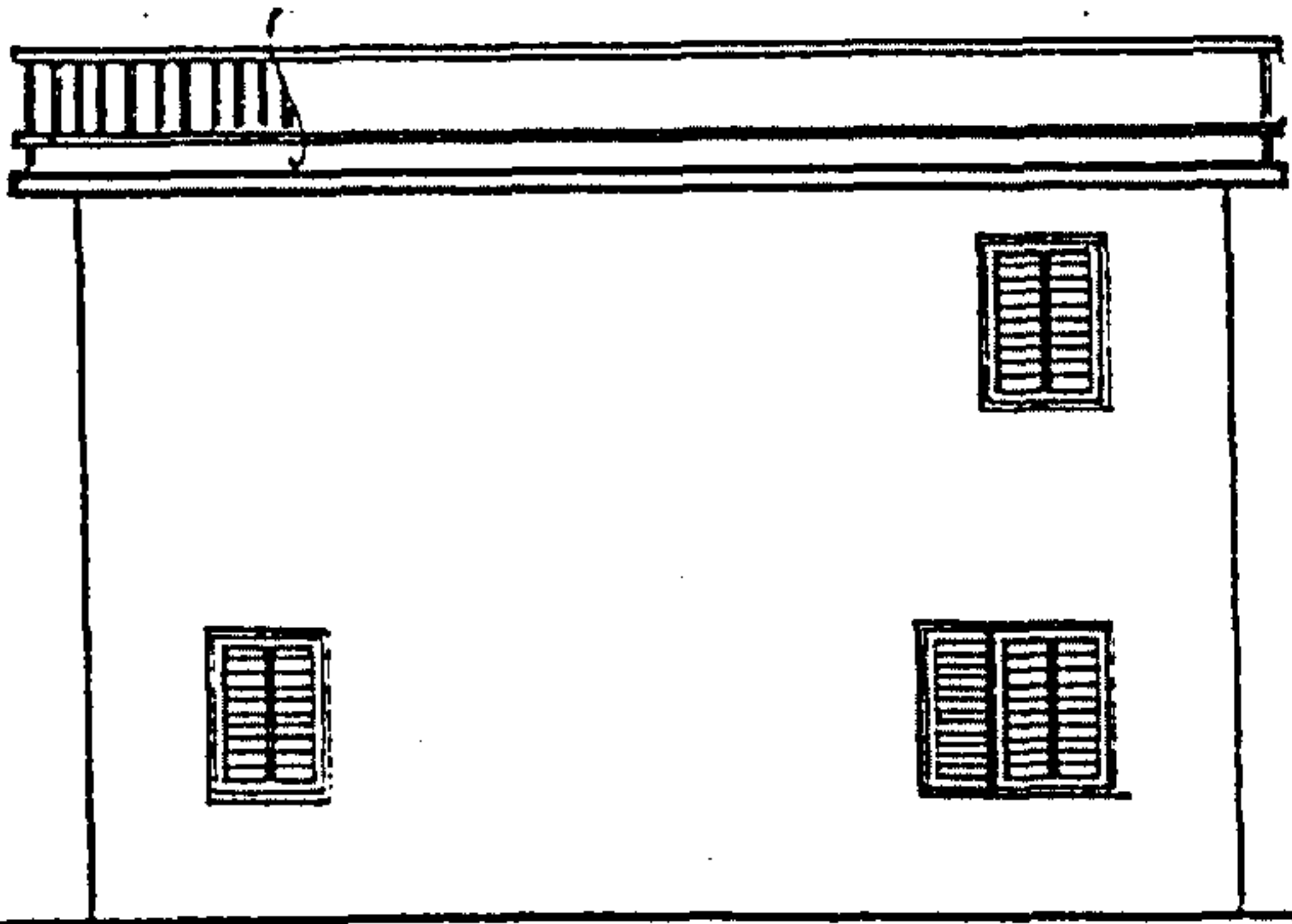
SOUTH ELEVATION



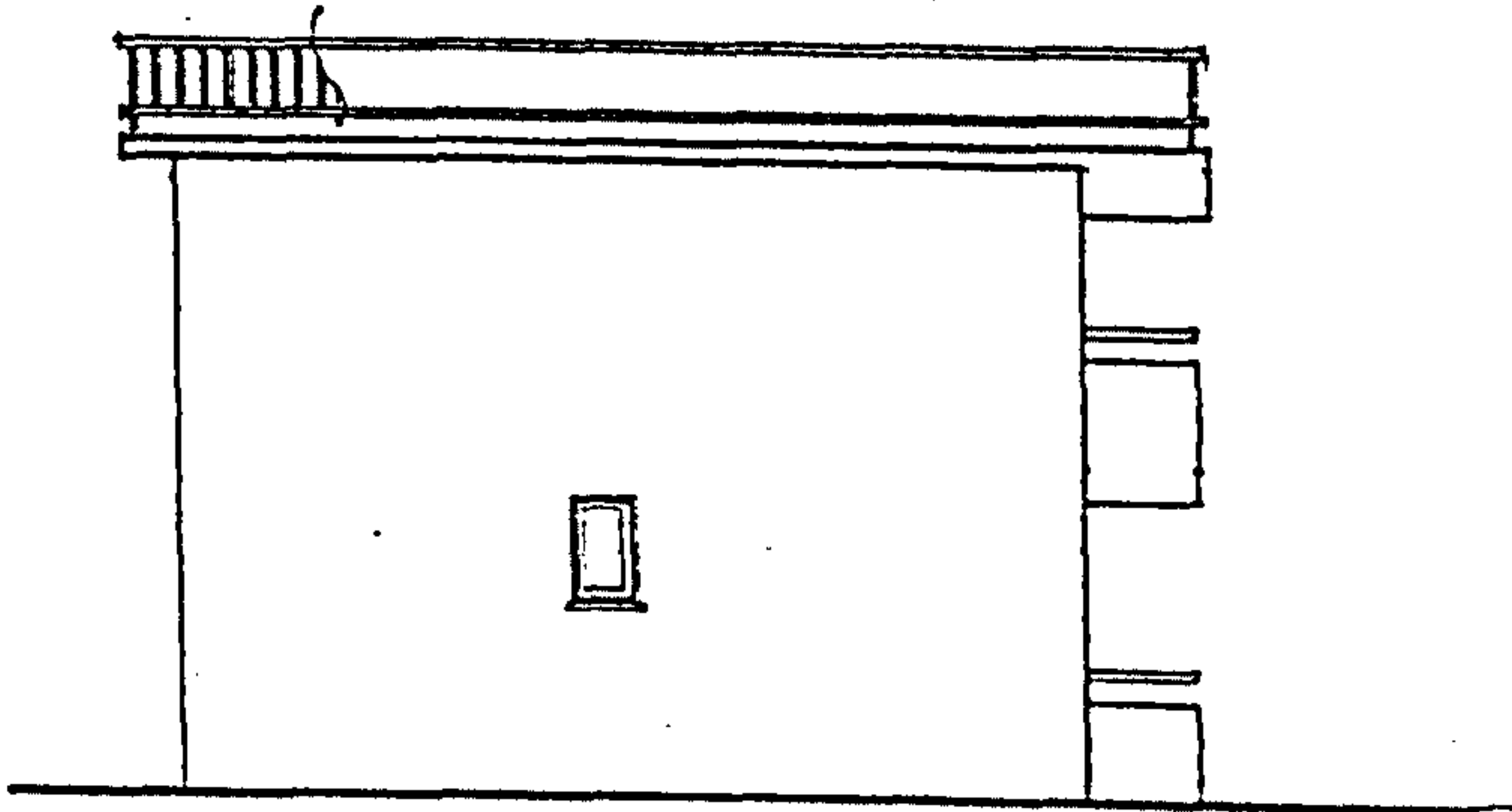
GROUND FLOOR



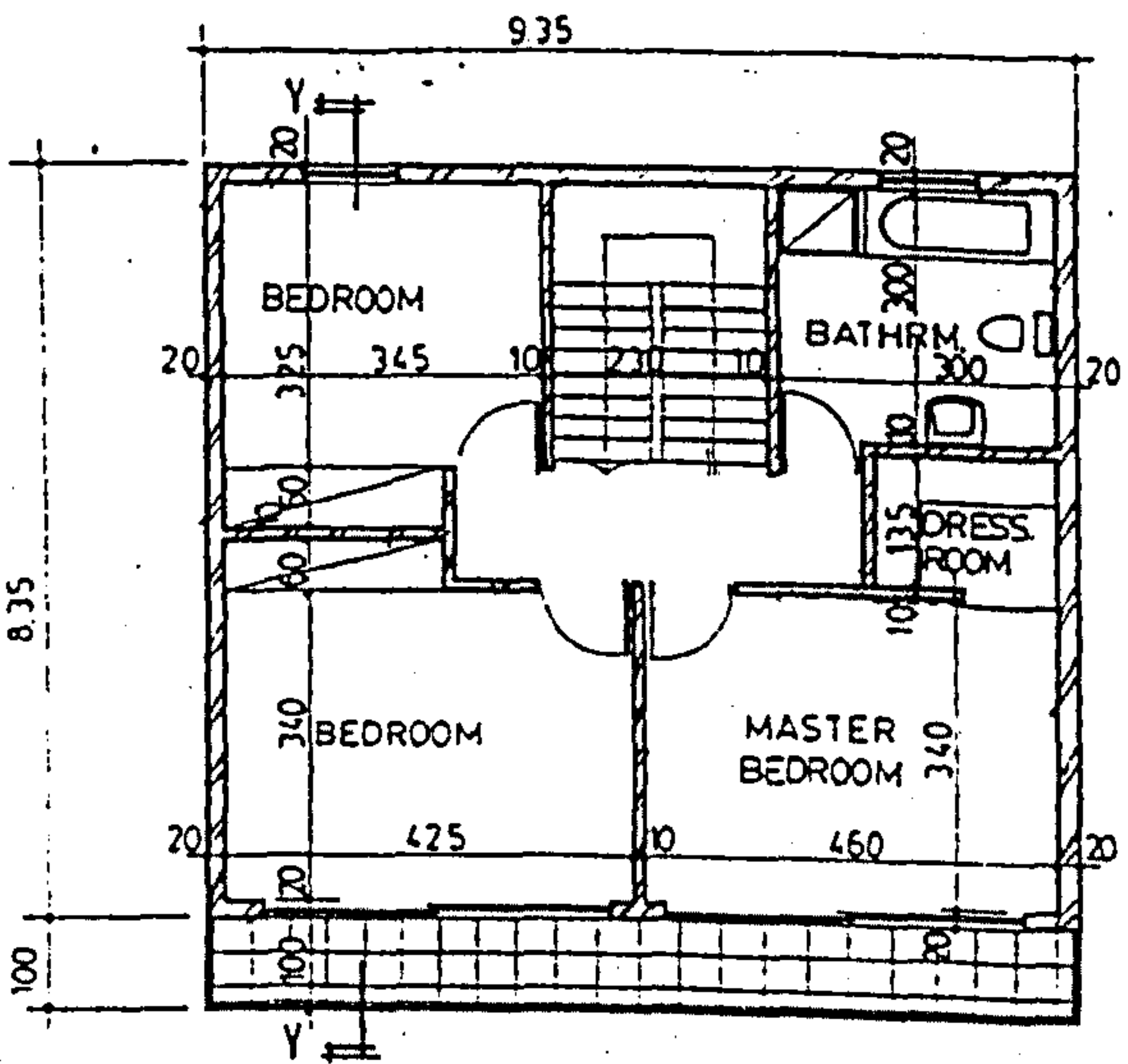
SECTION Y-Y



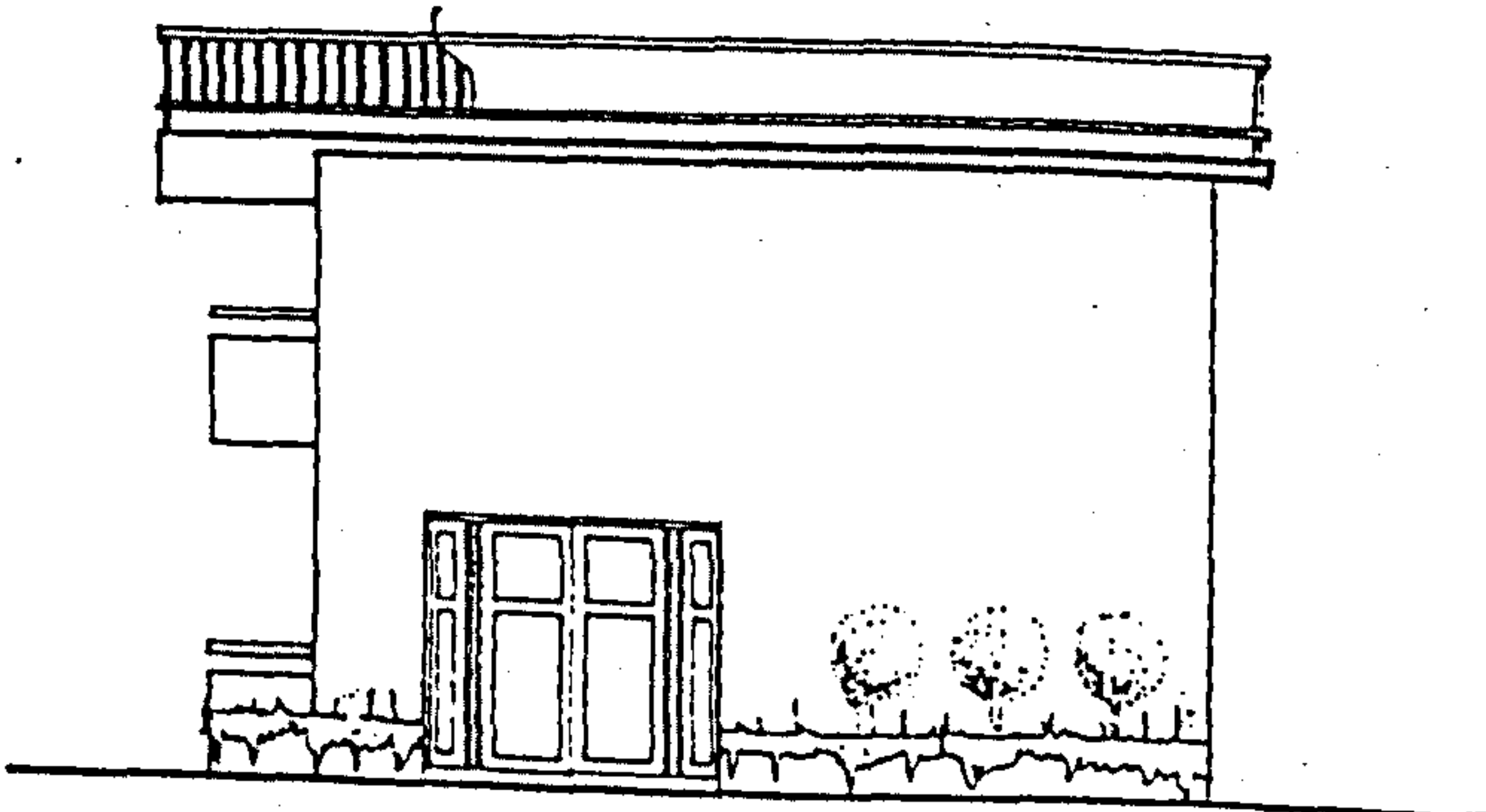
NORTH ELEVATION



WEST ELEVATION



FIRST FLOOR



EAST ELEVATION

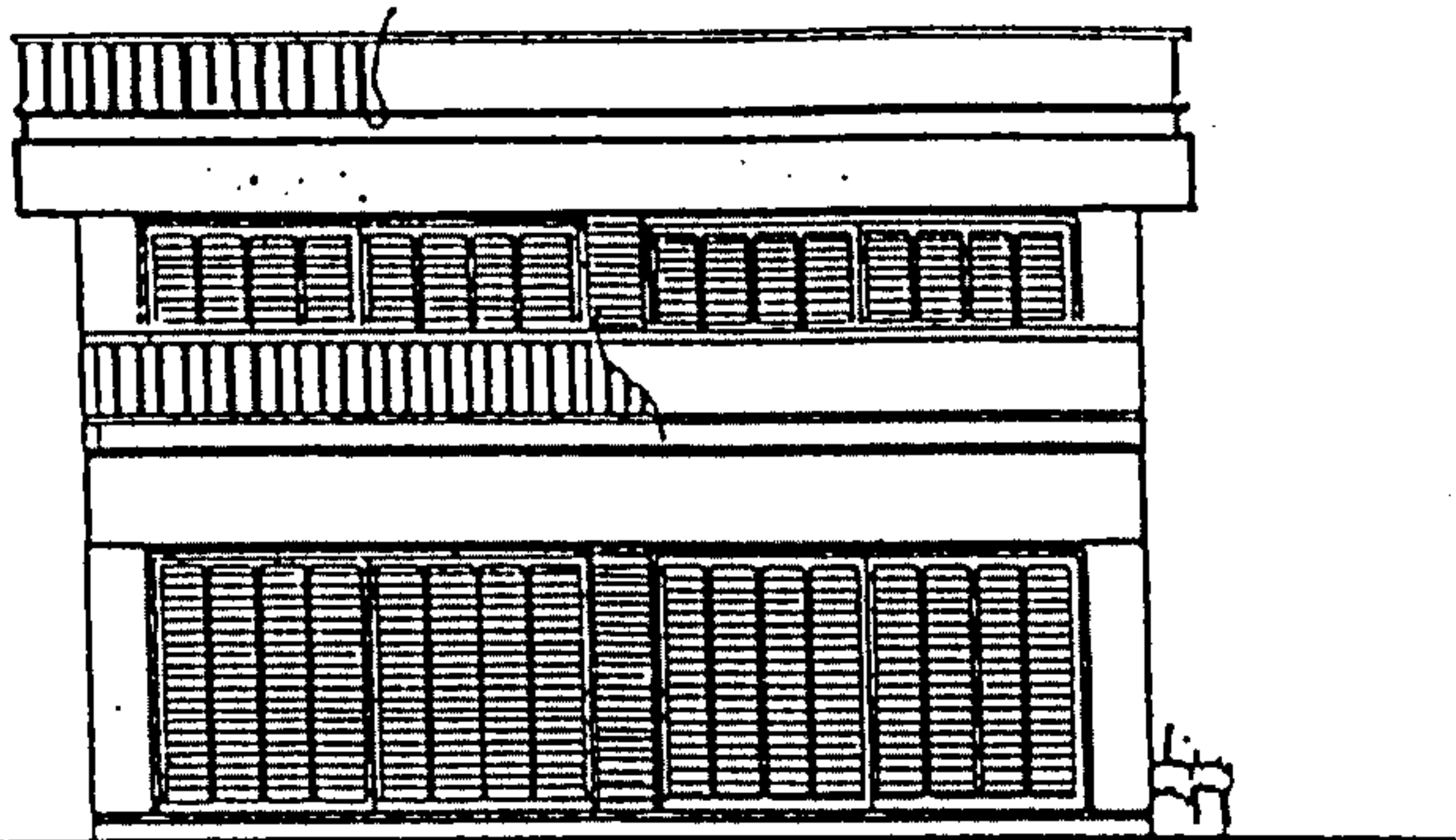


TEST NO: S2

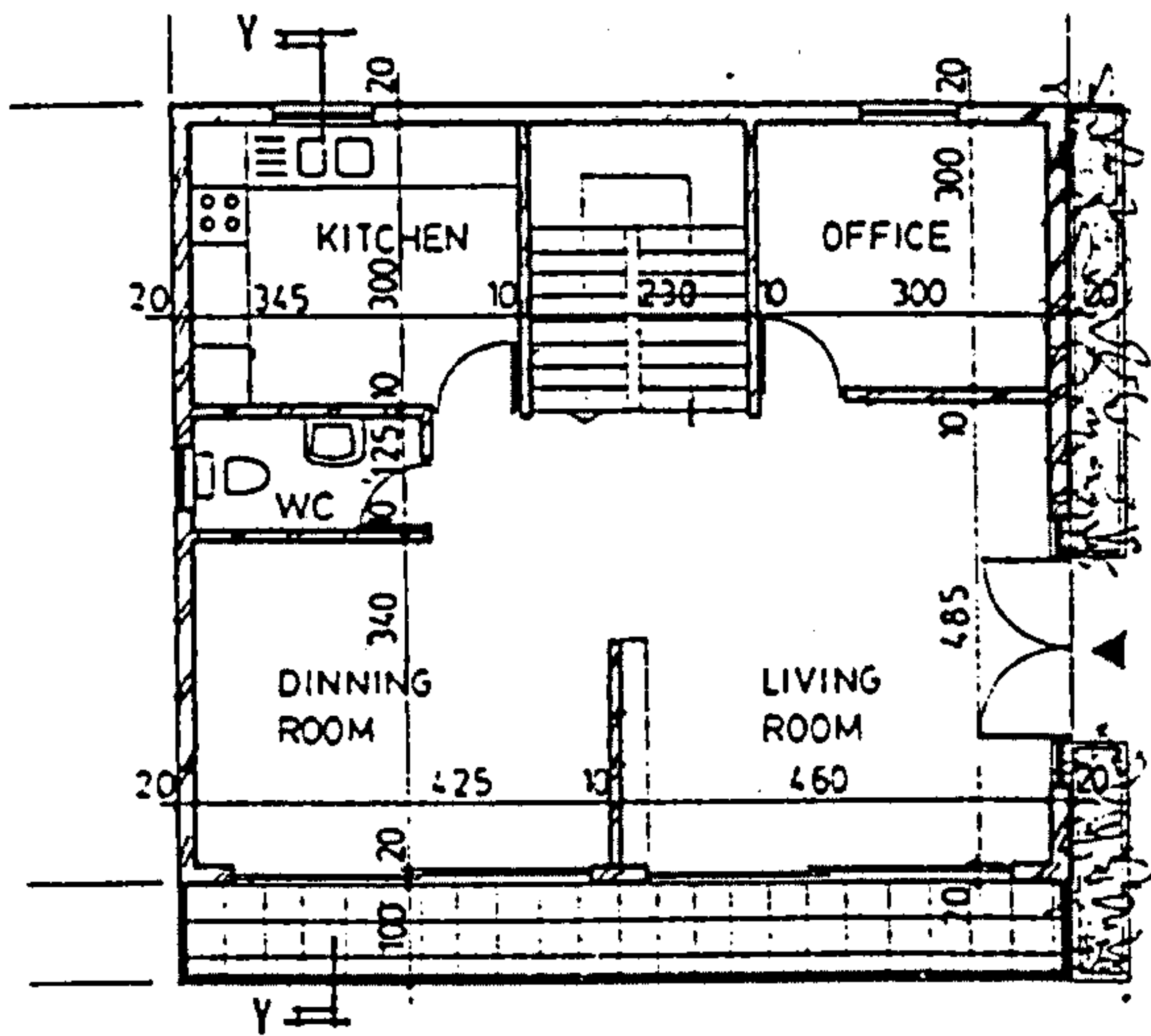
PLANS-SECTIONS-ELEVATION

DESIGN PARAMETER:Window Area

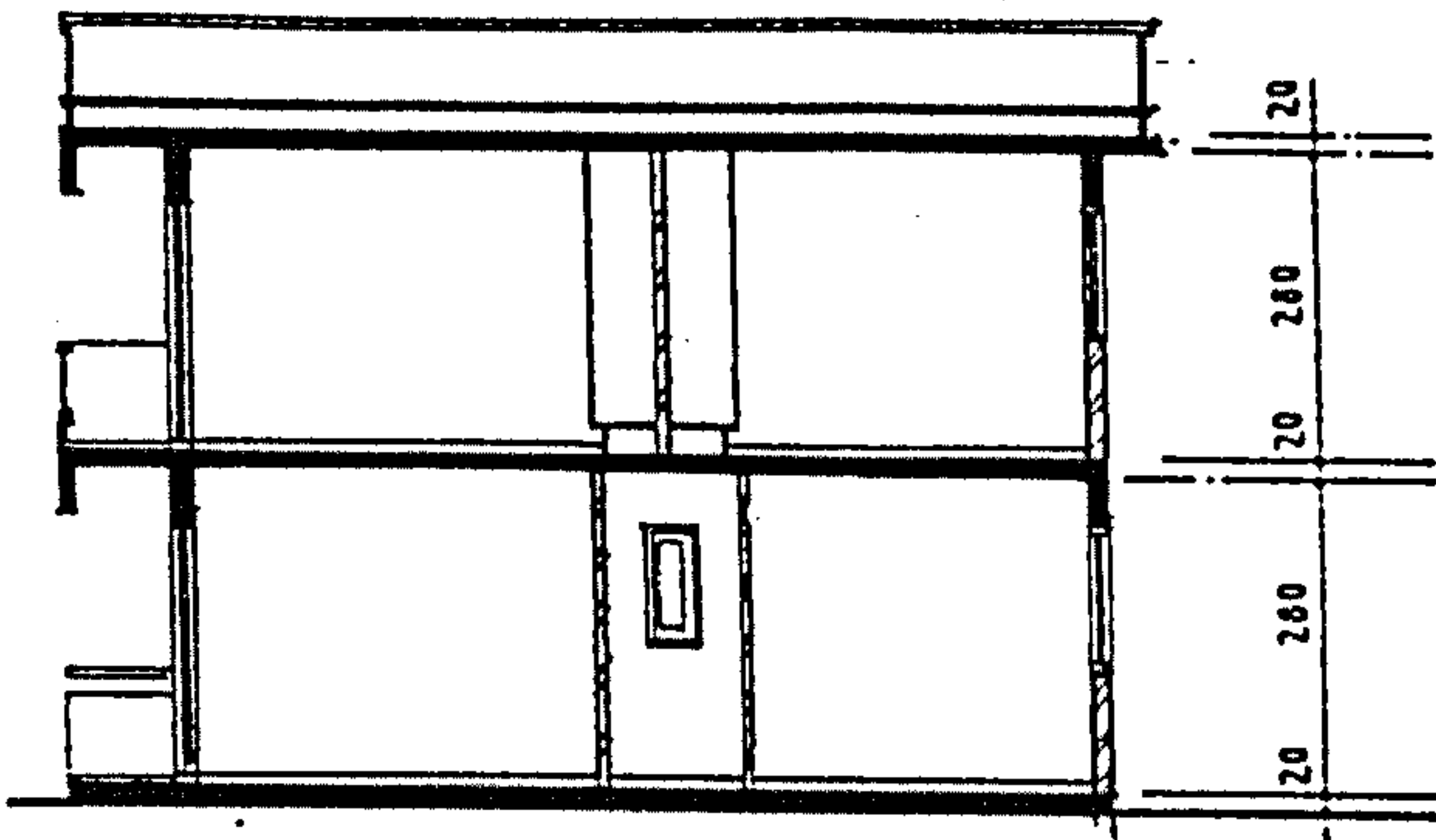
Adding -  $5\text{m}^2$  Sth



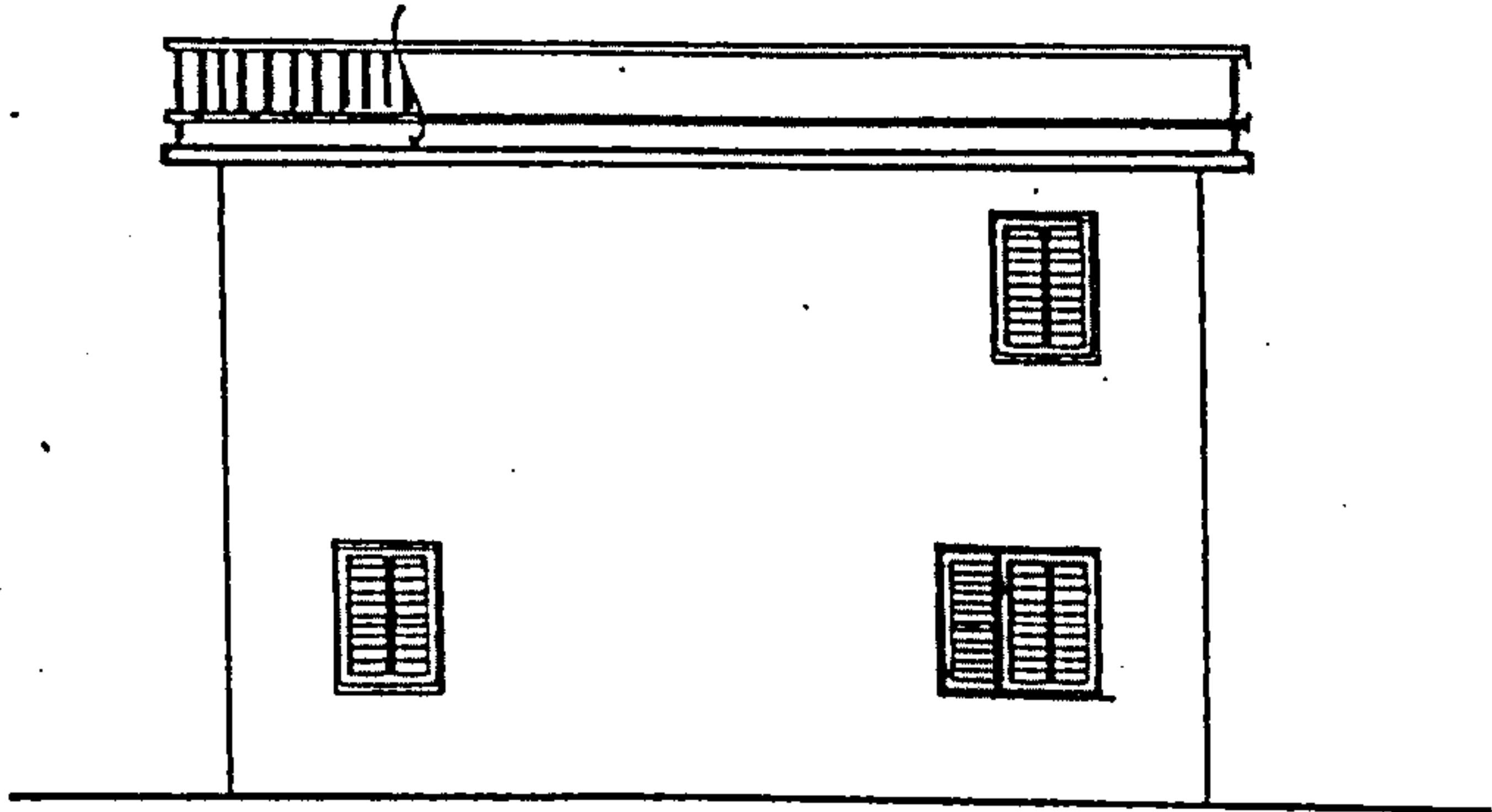
SOUTH ELEVATION



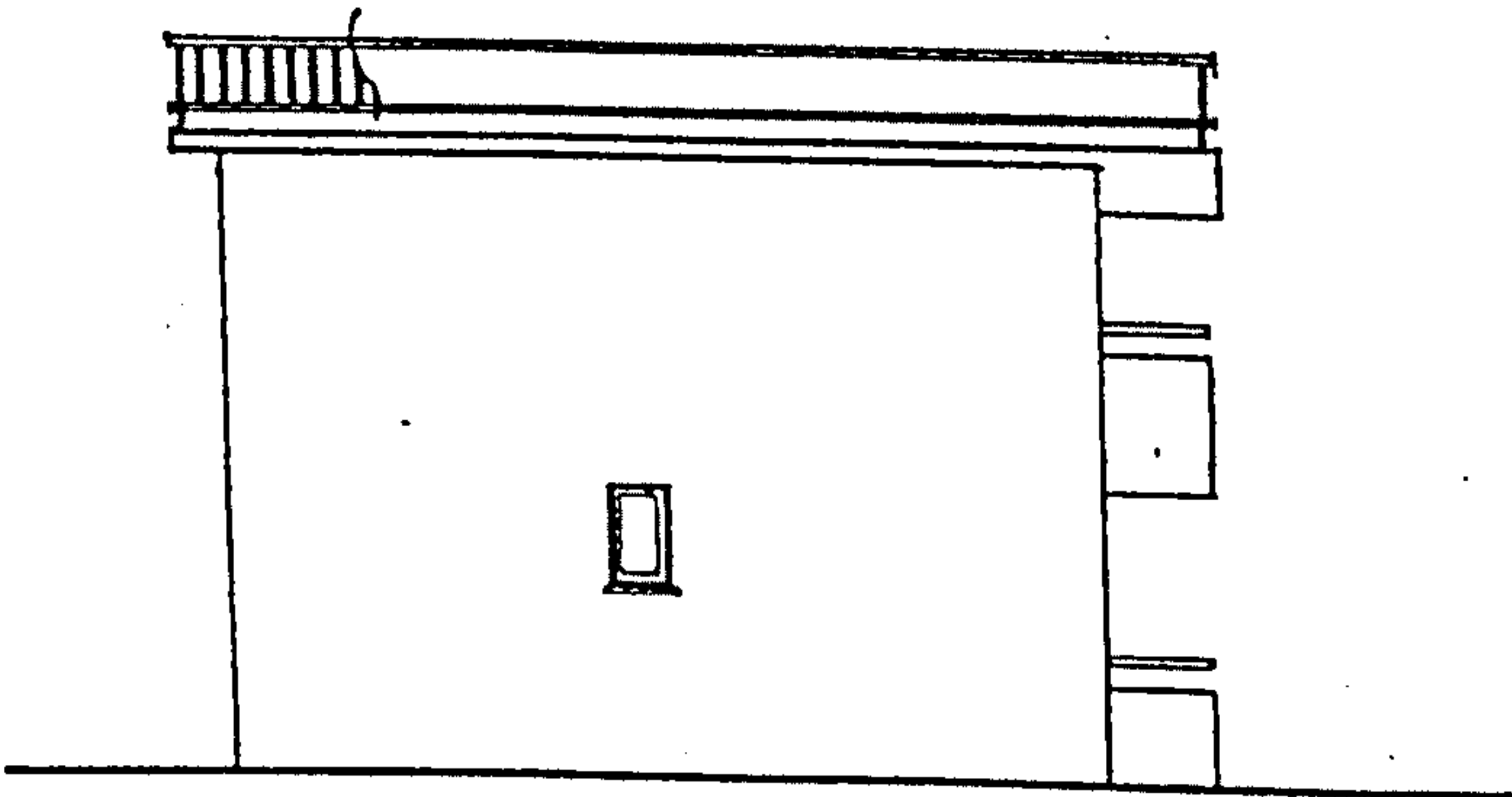
GROUND FLOOR



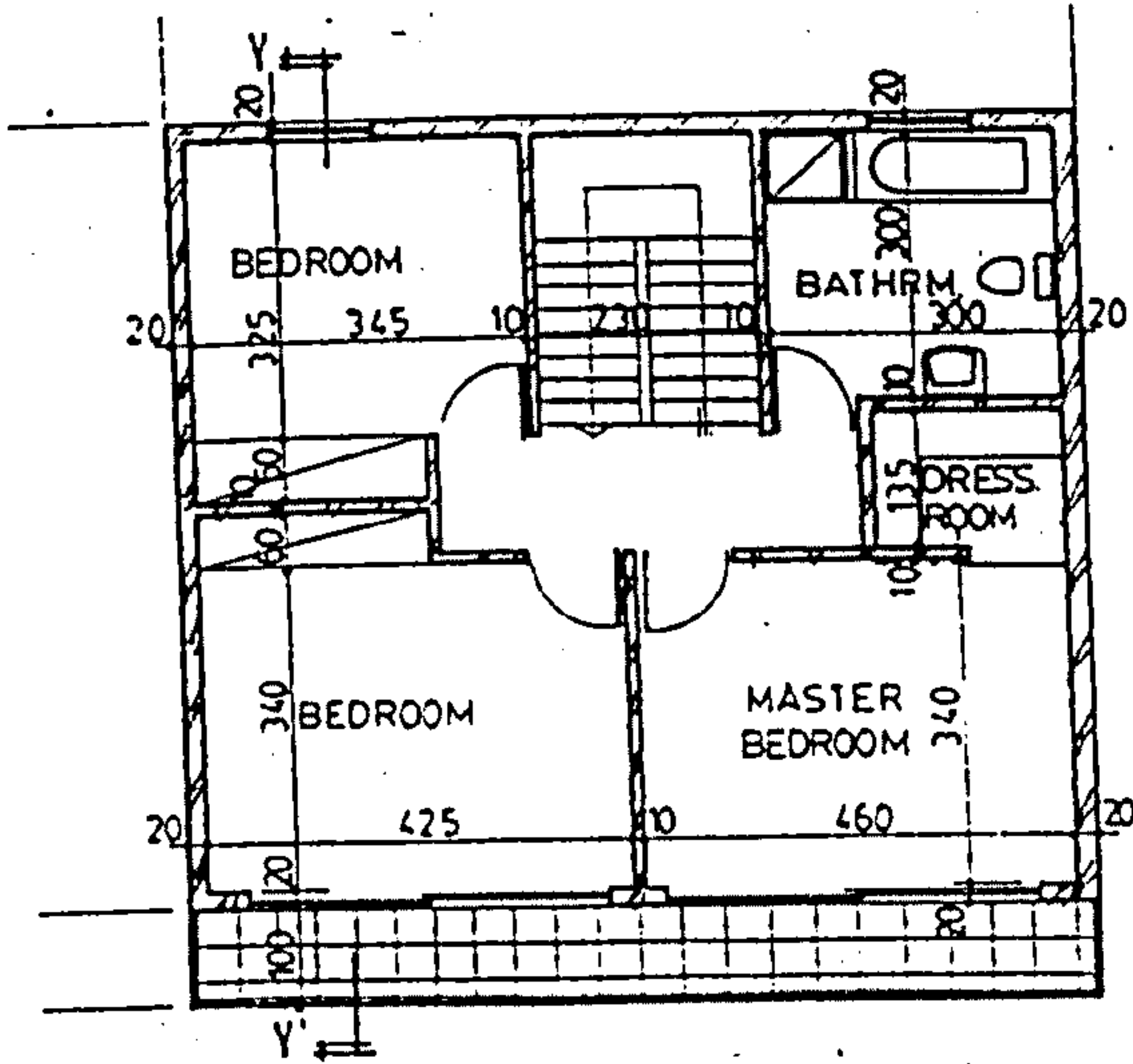
SECTION Y-Y



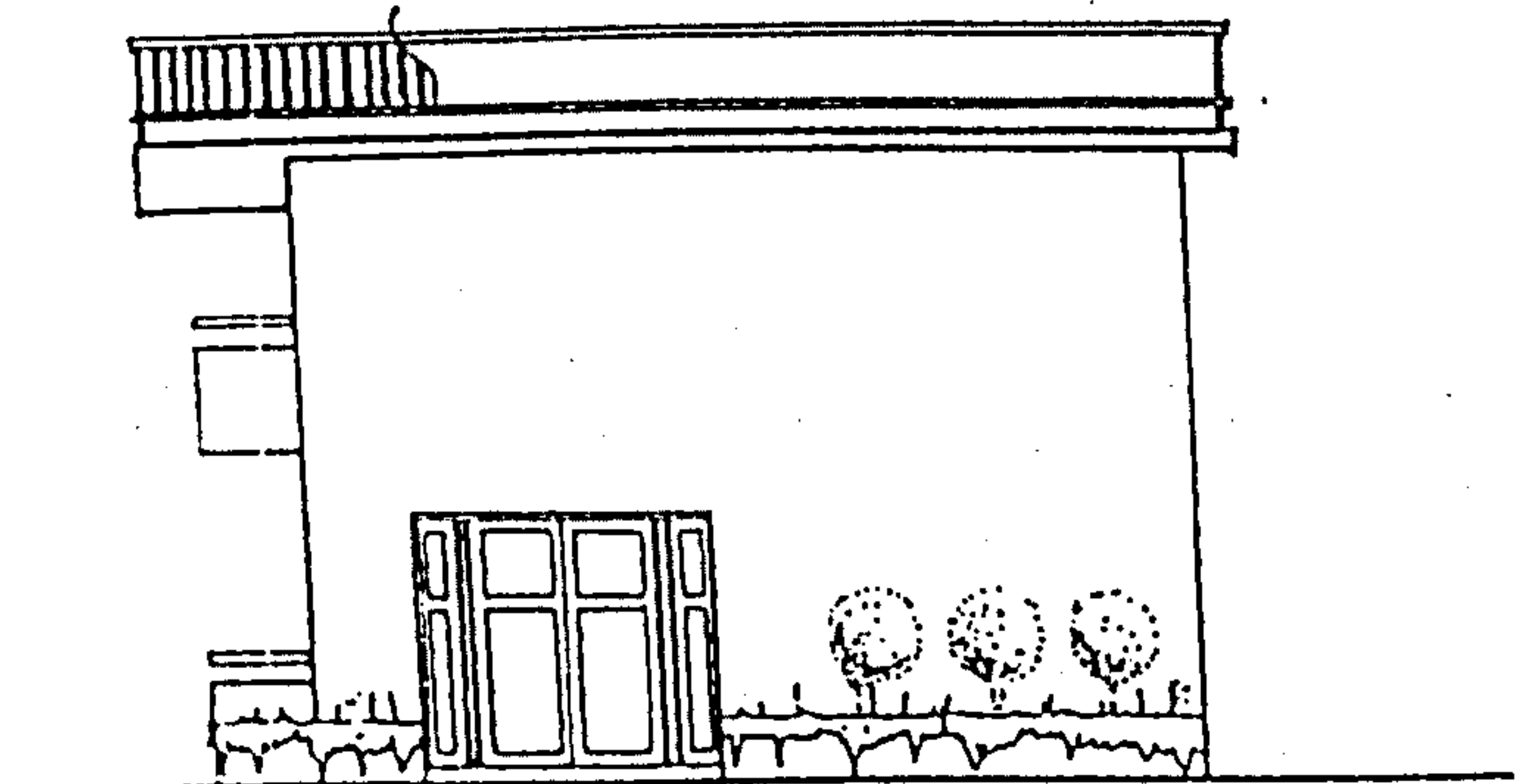
NORTH ELEVATION



WEST ELEVATION

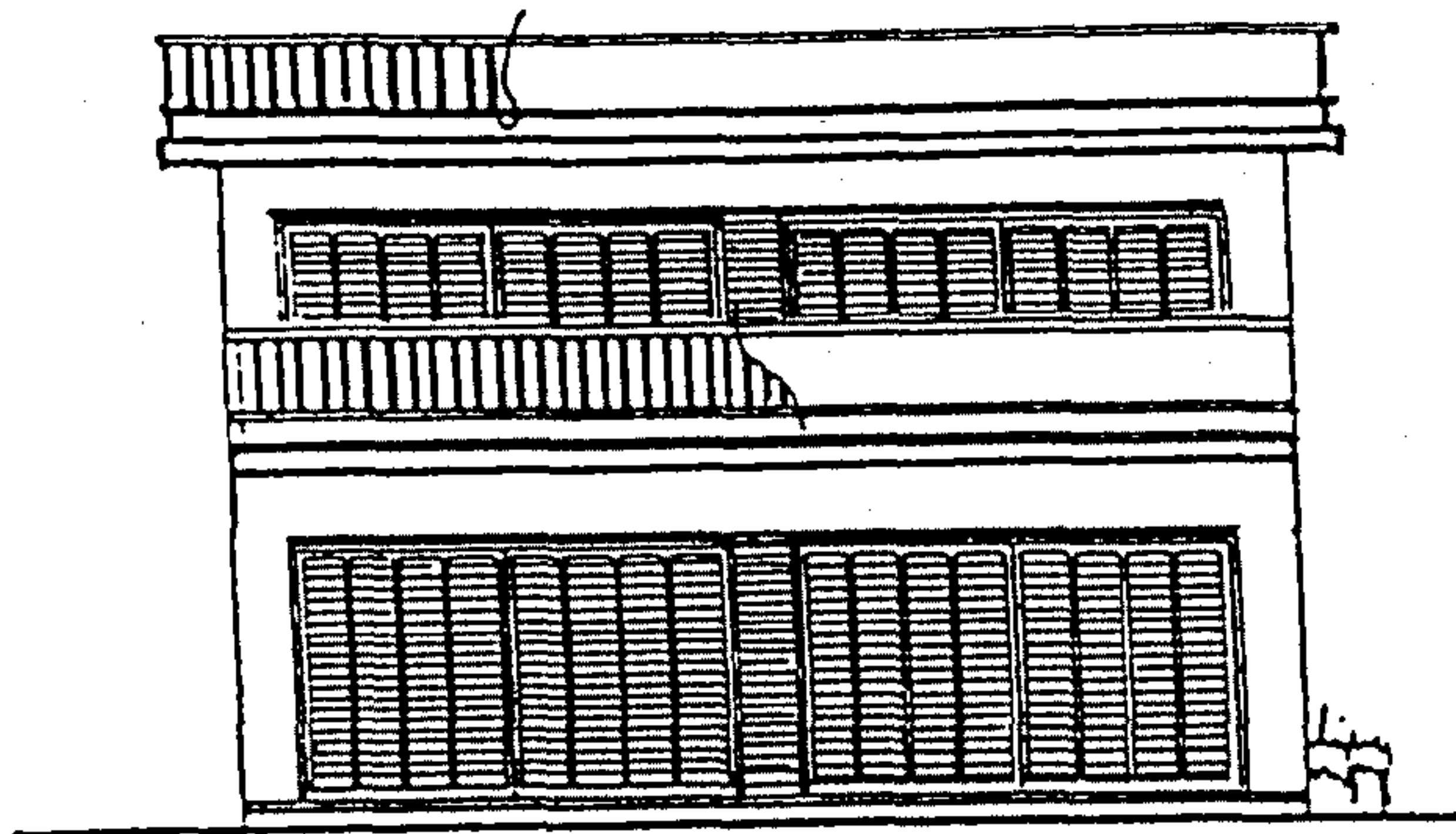


FIRST FLOOR



EAST ELEVATION





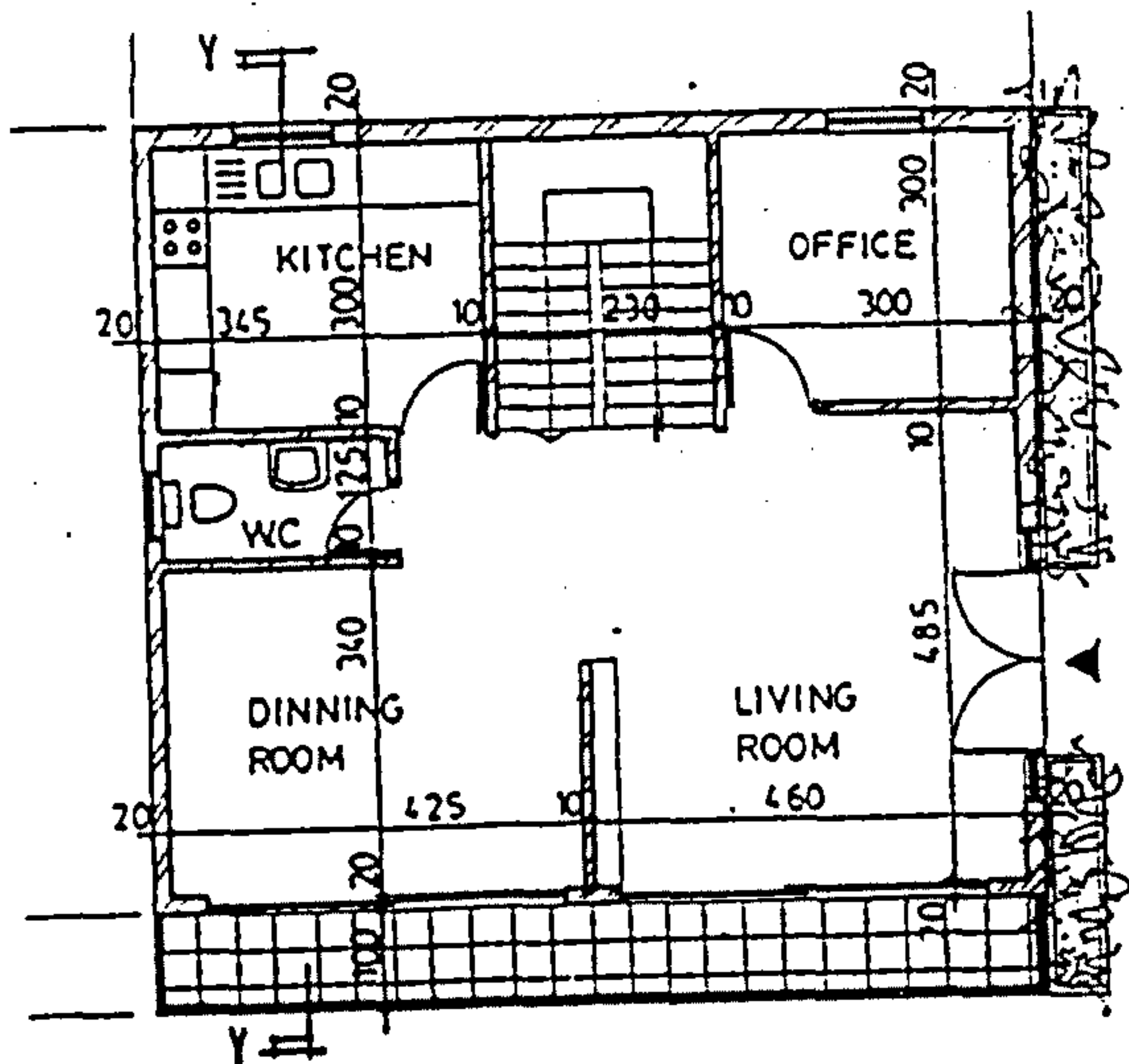
SOUTH ELEVATION

TEST NO: S3

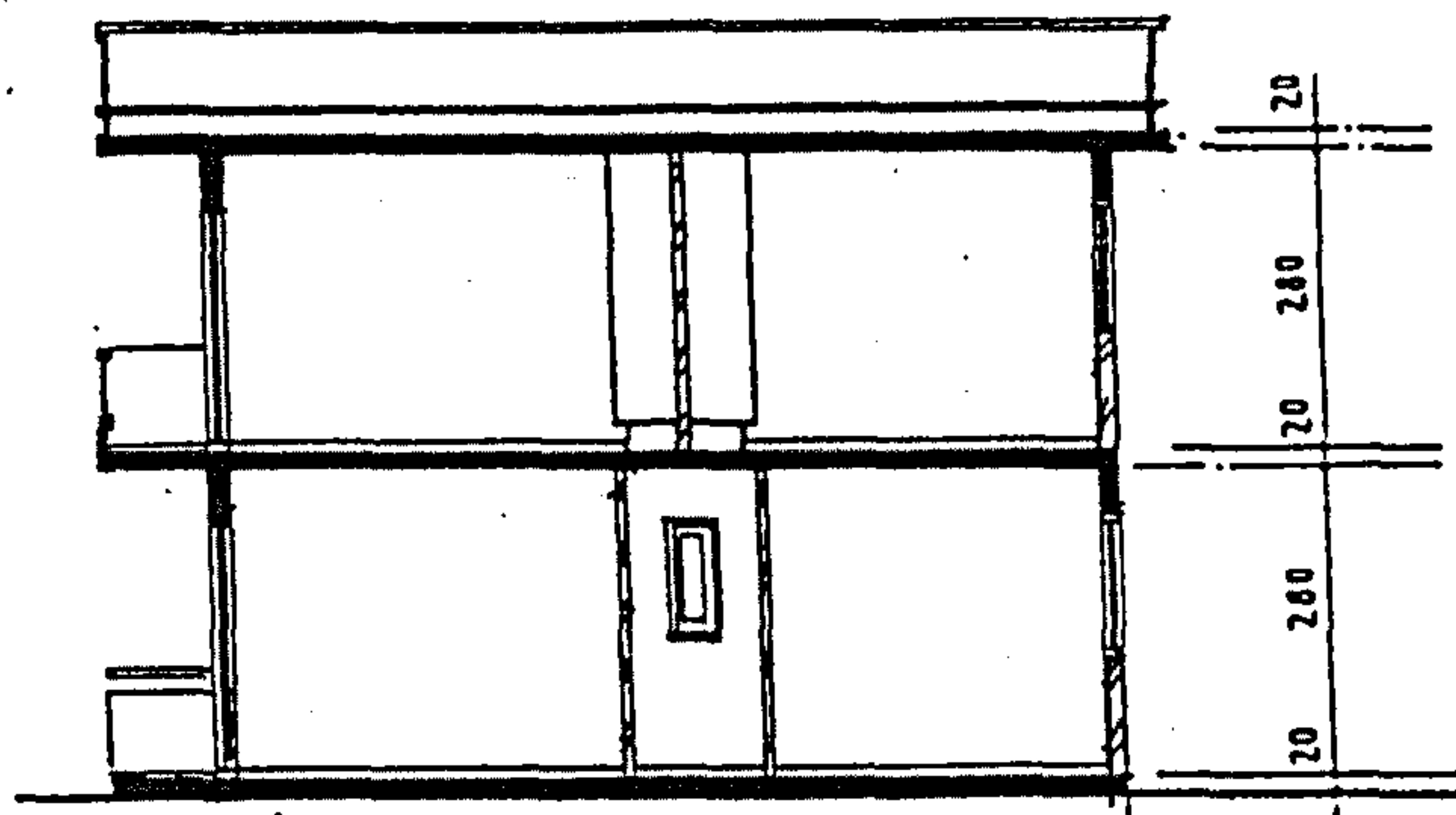
PLANS-SECTIONS-ELEVATIONS

DESIGN PARAMETER: GLAZING (shade)

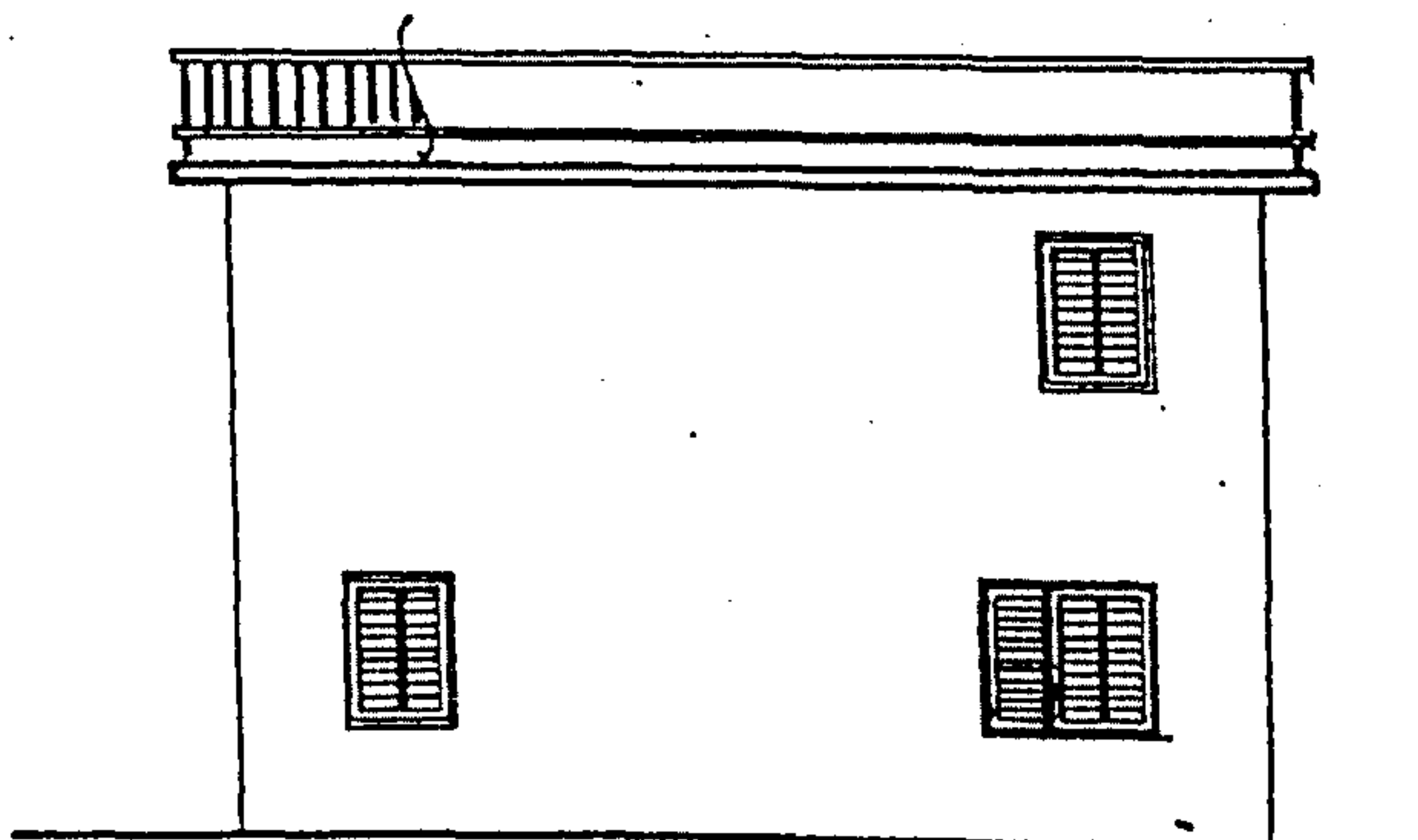
Overhang raised by 50cm



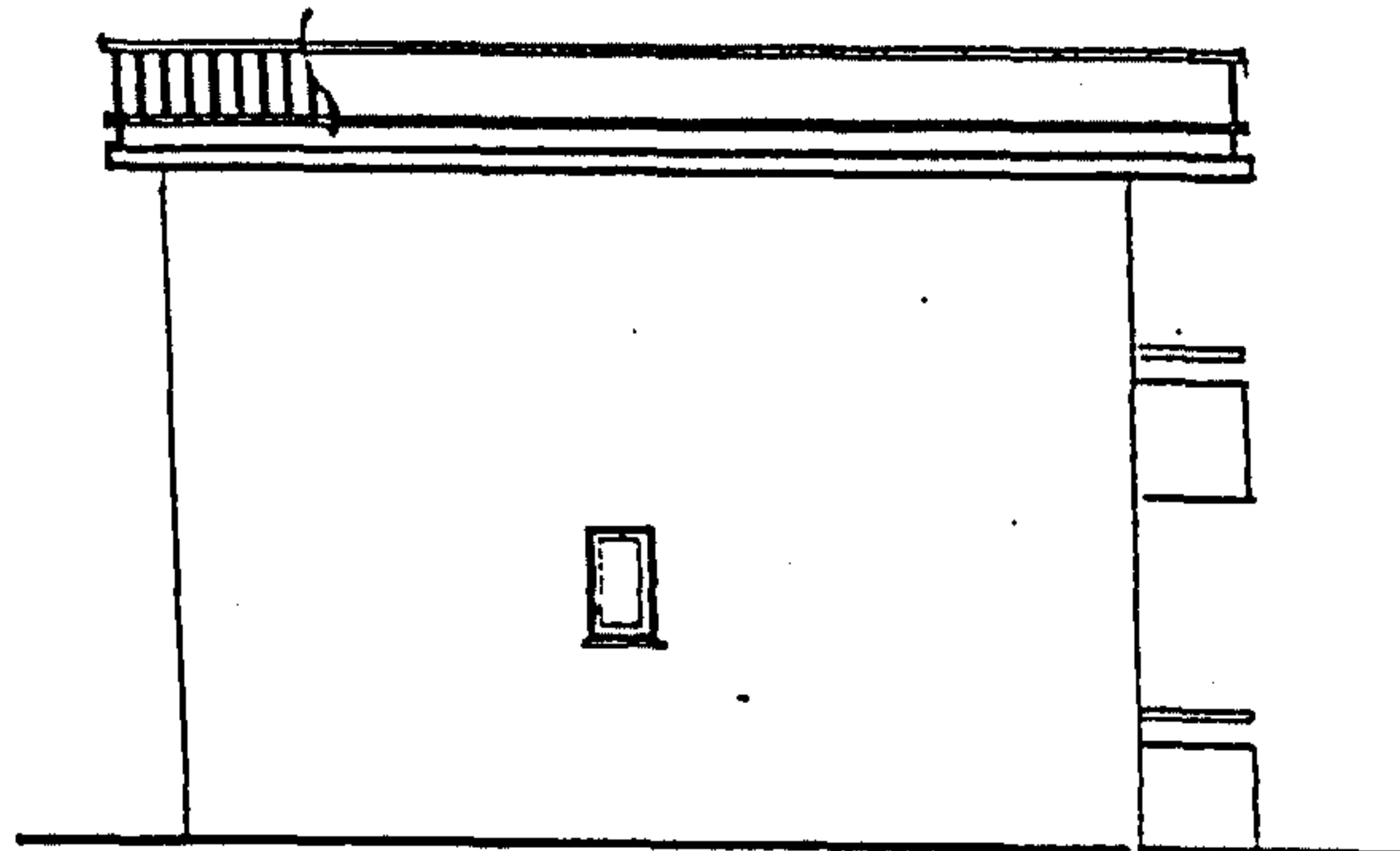
GROUND FLOOR



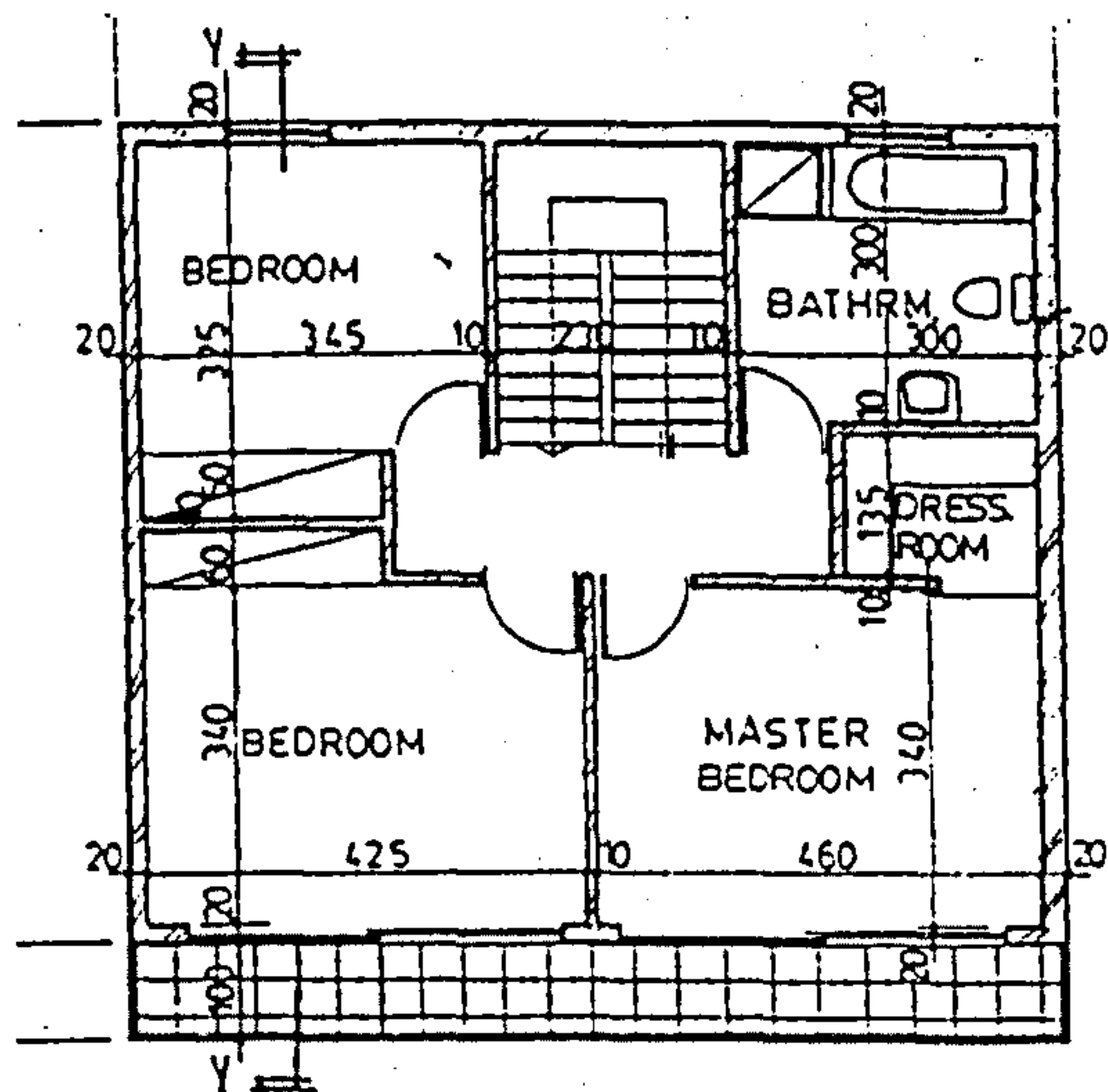
SECTION Y-Y



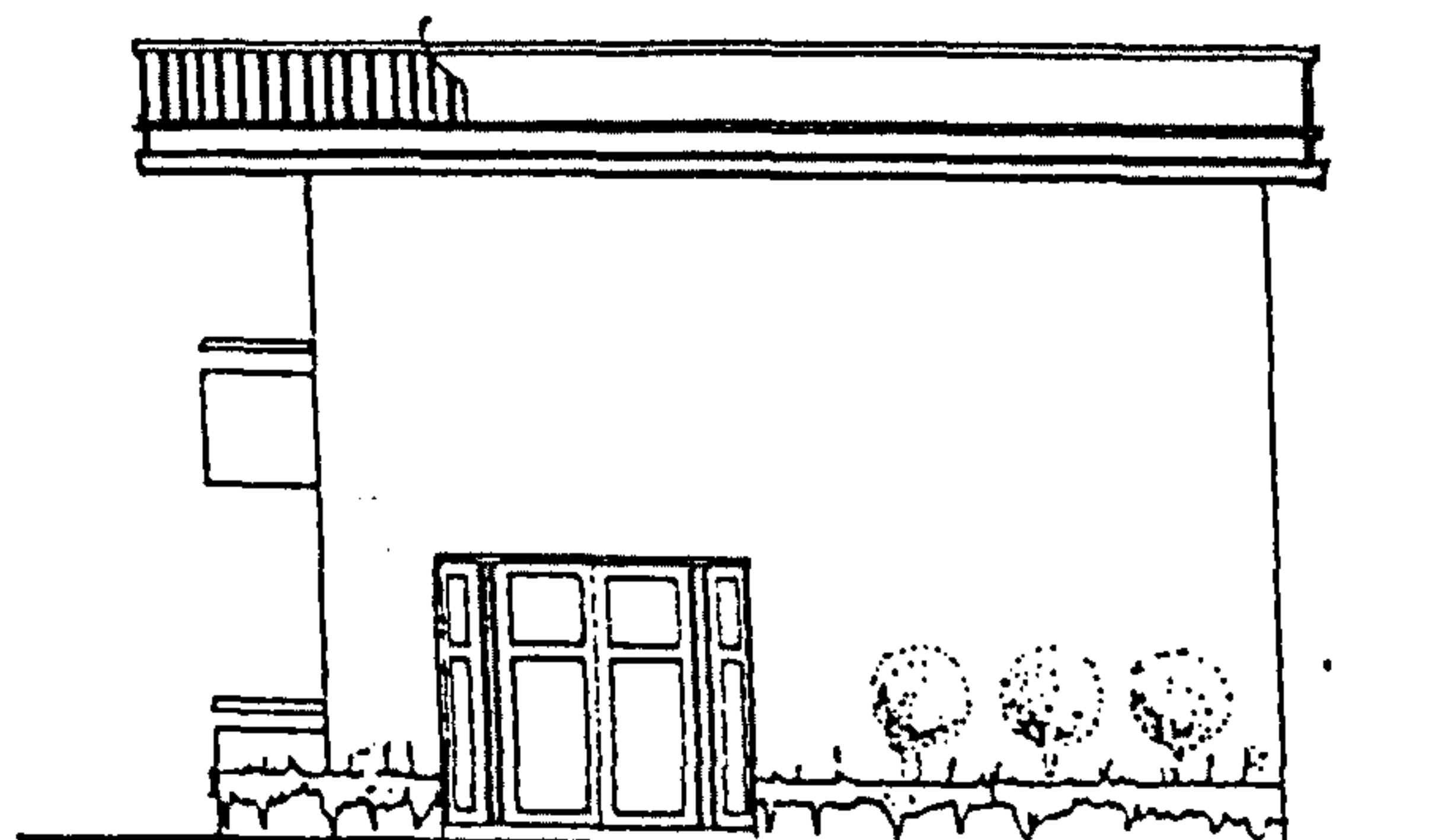
NORTH ELEVATION



WEST ELEVATION



FIRST FLOOR

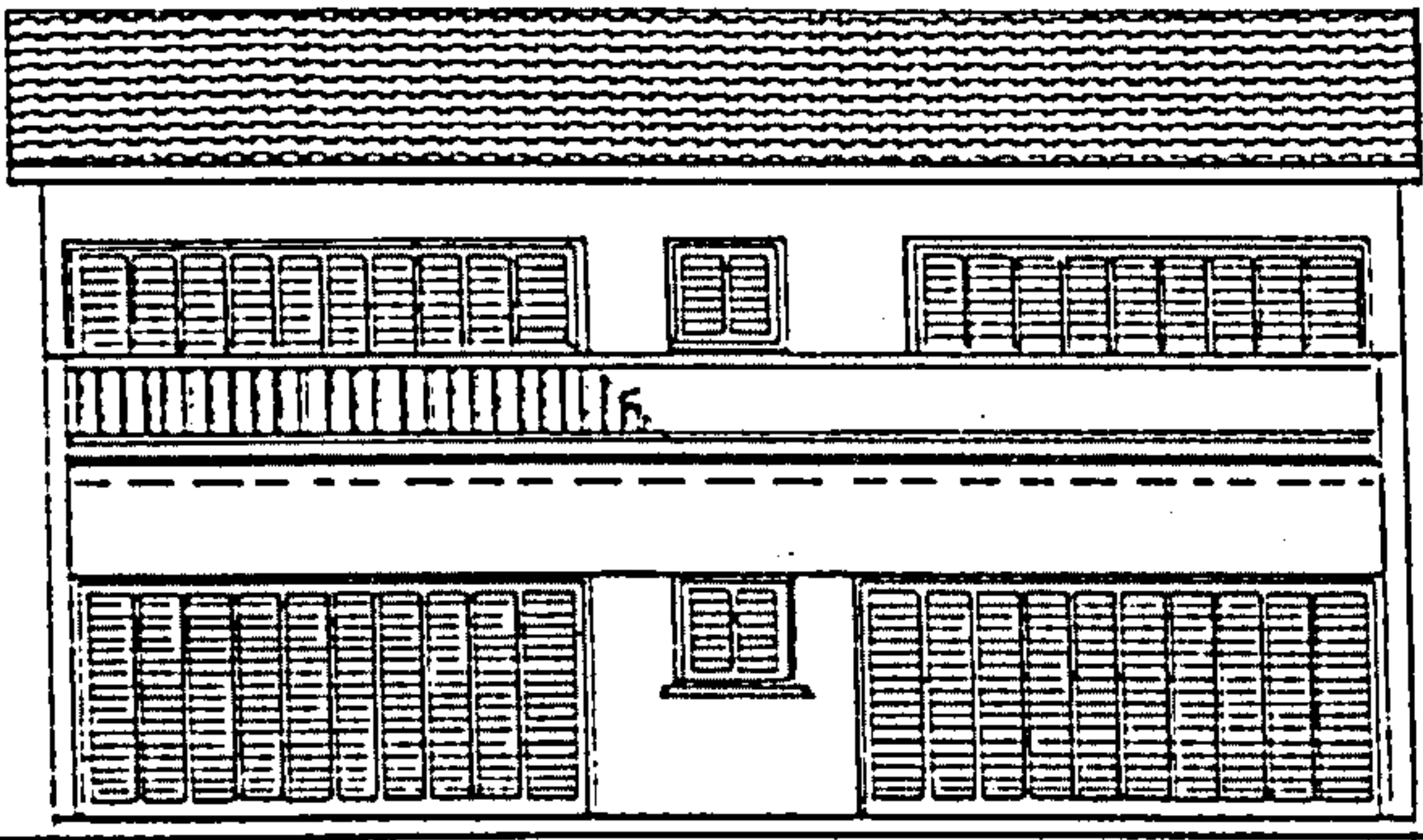


EAST ELEVATION

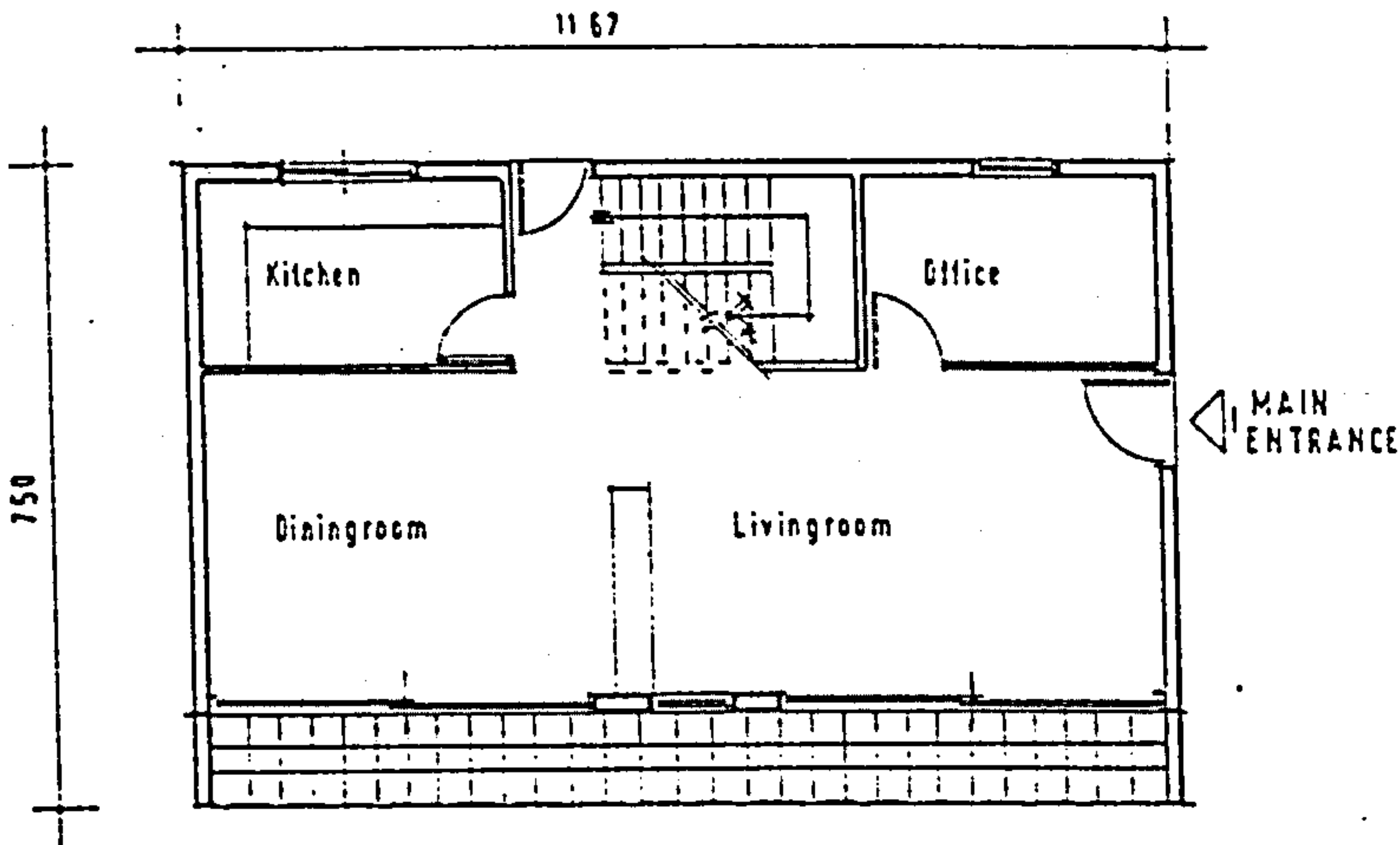


TEST NO: S7

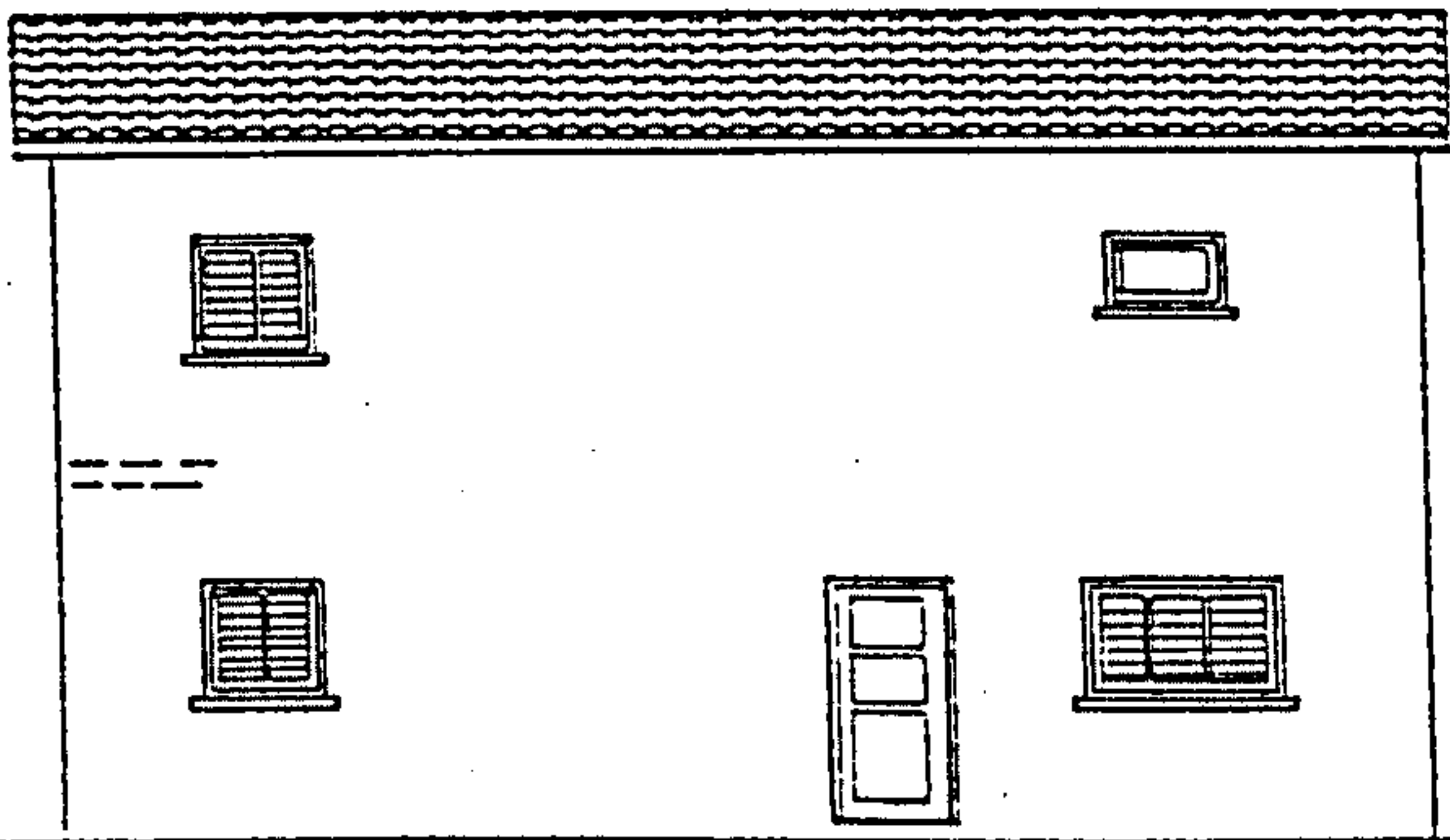
DESING PARAMETER: SHAPE



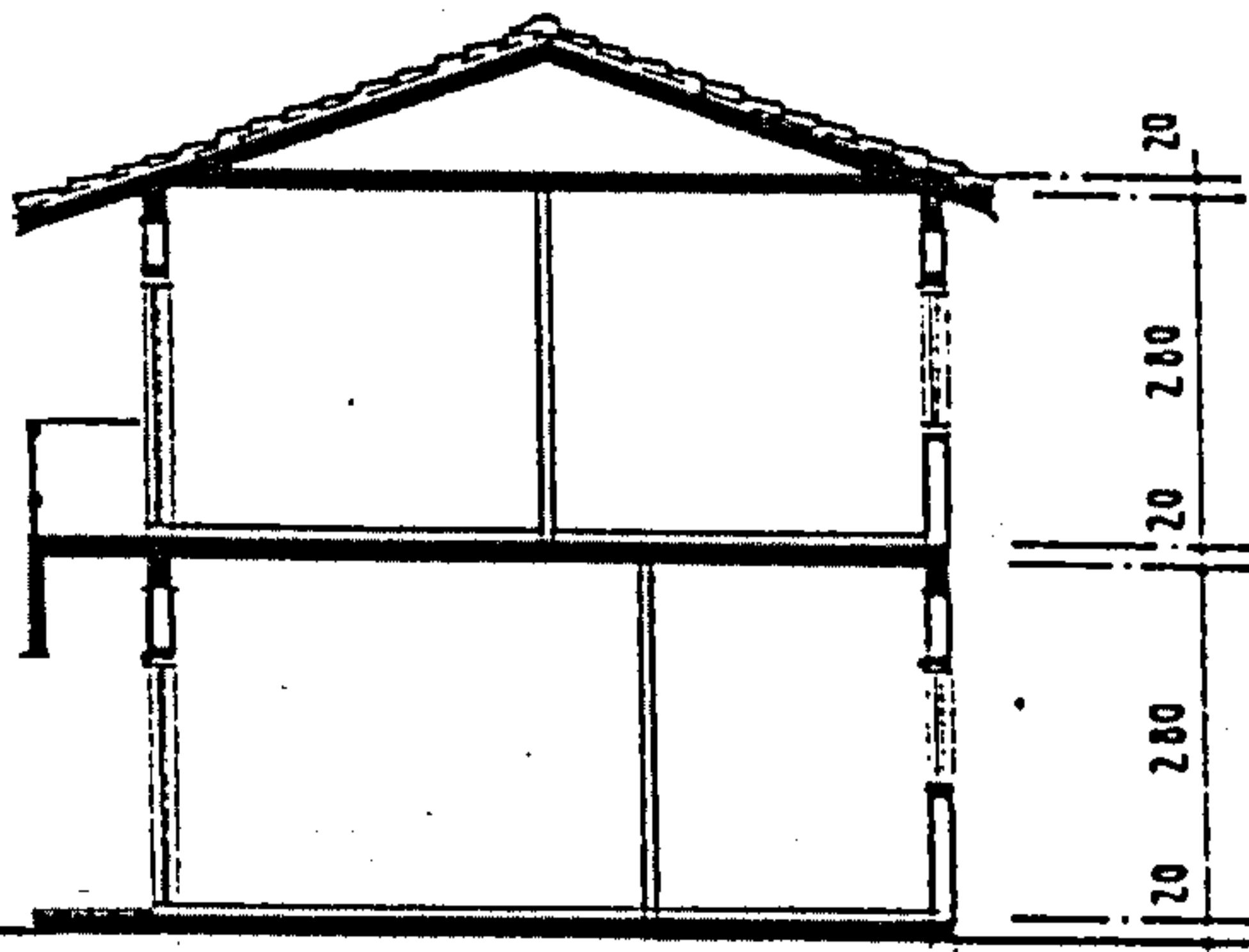
FRONT ELEVATION



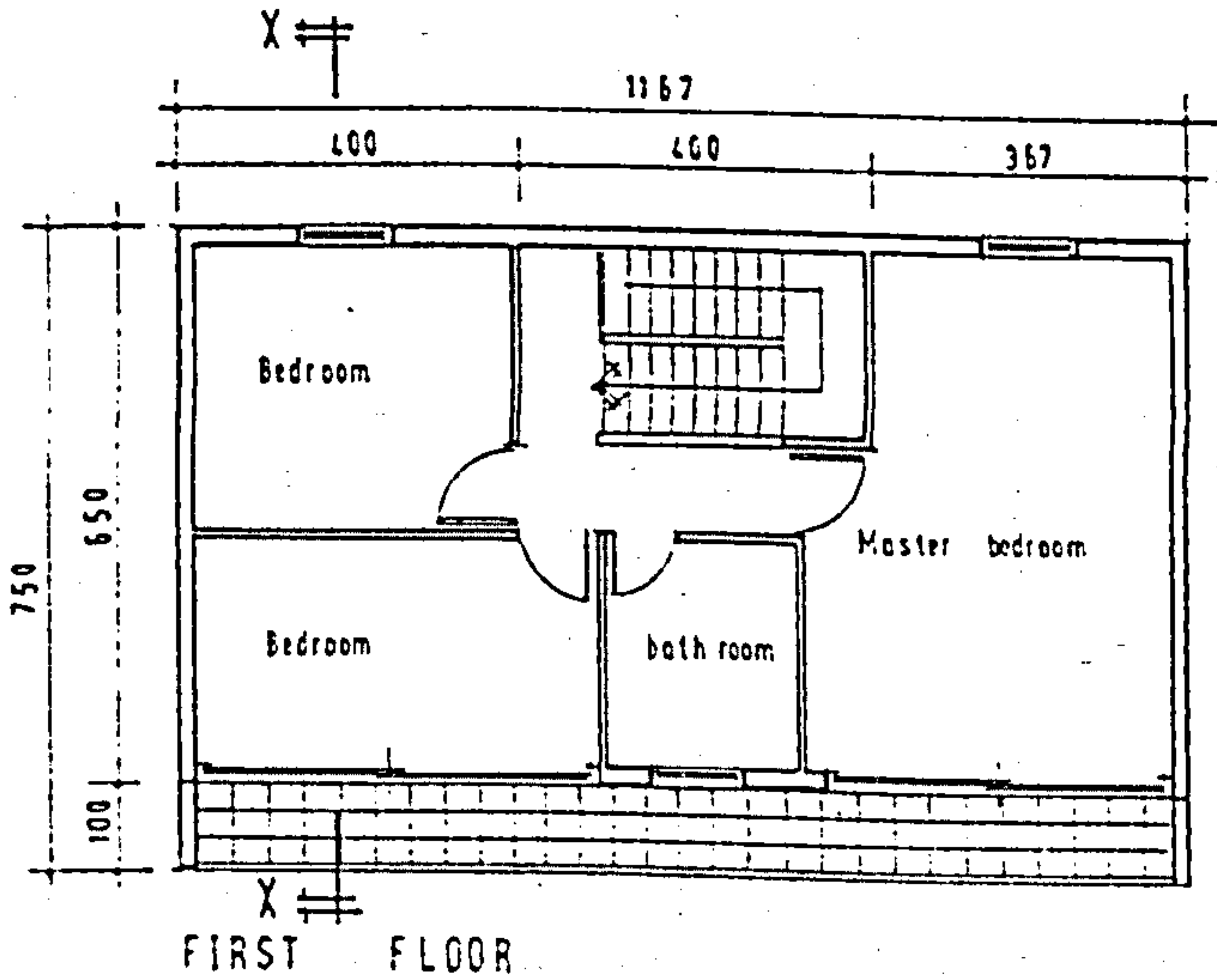
GROUND FLOOR



REAR ELEVATION



SECTION X-X



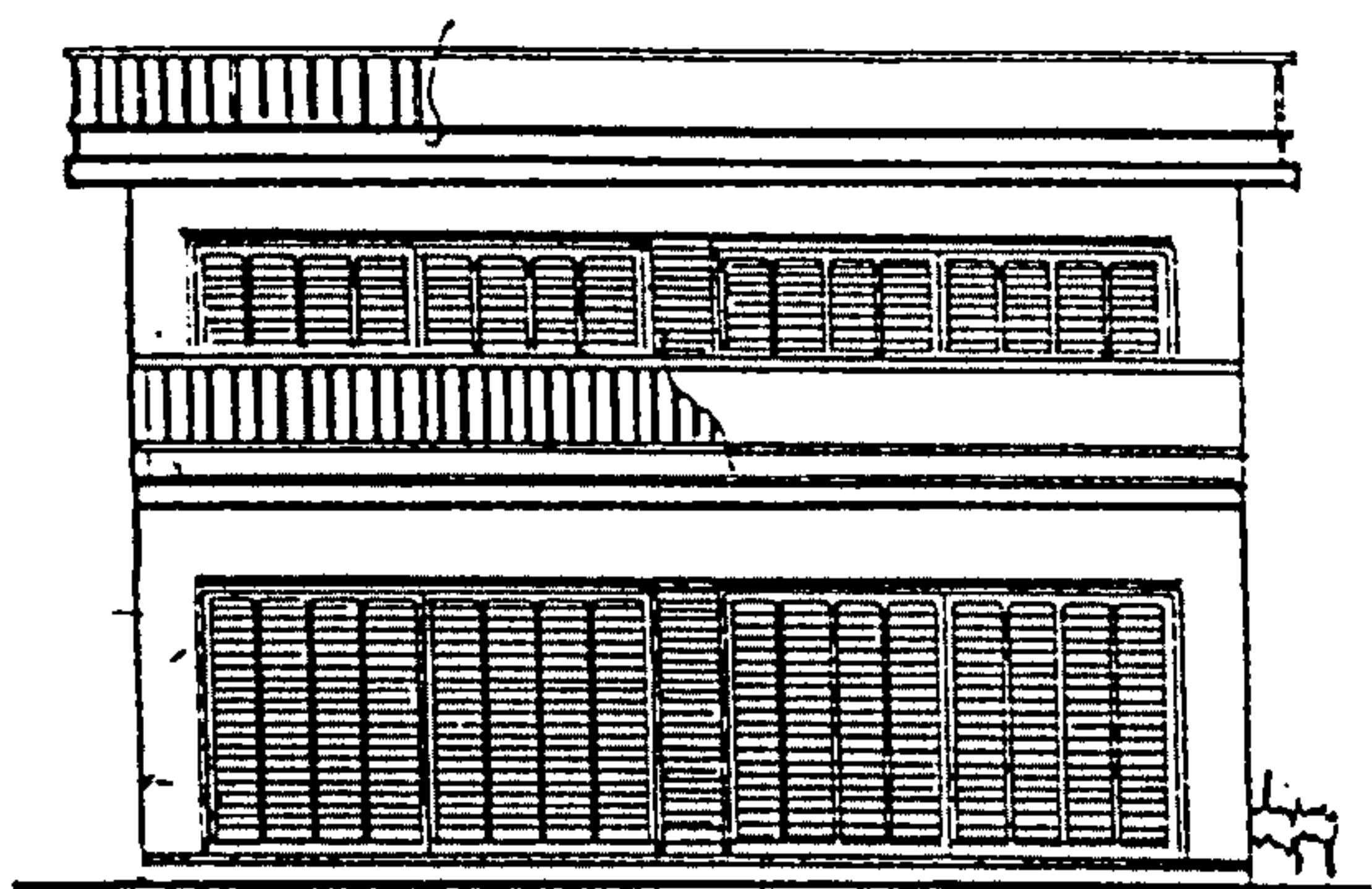
FIRST FLOOR



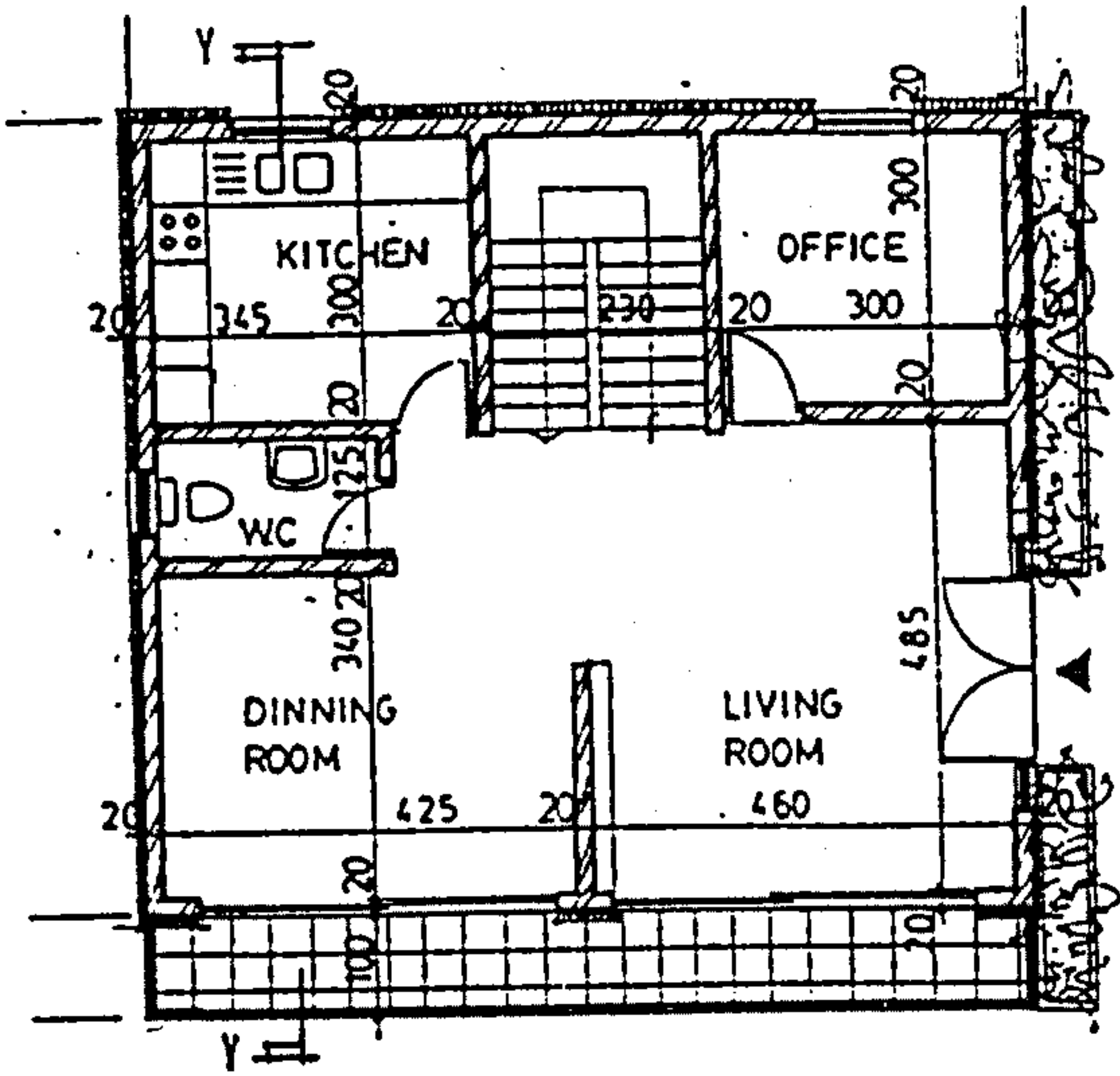
TEST NO: S16

DESIGN PARAMETER: GLAZING

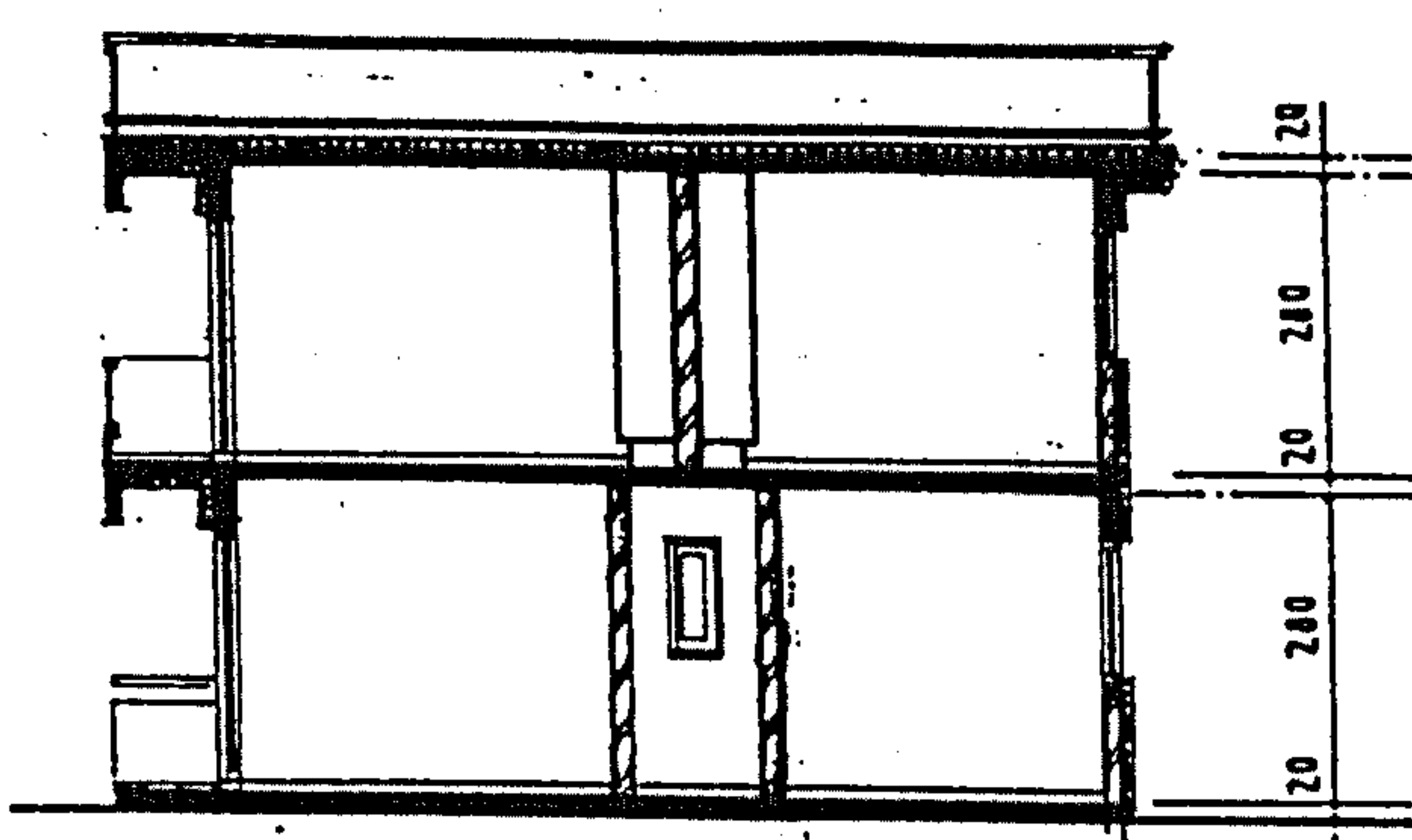
Increasing NRTH Glazing by 50%  
from 3.5m<sup>2</sup> to 7.0m<sup>2</sup>



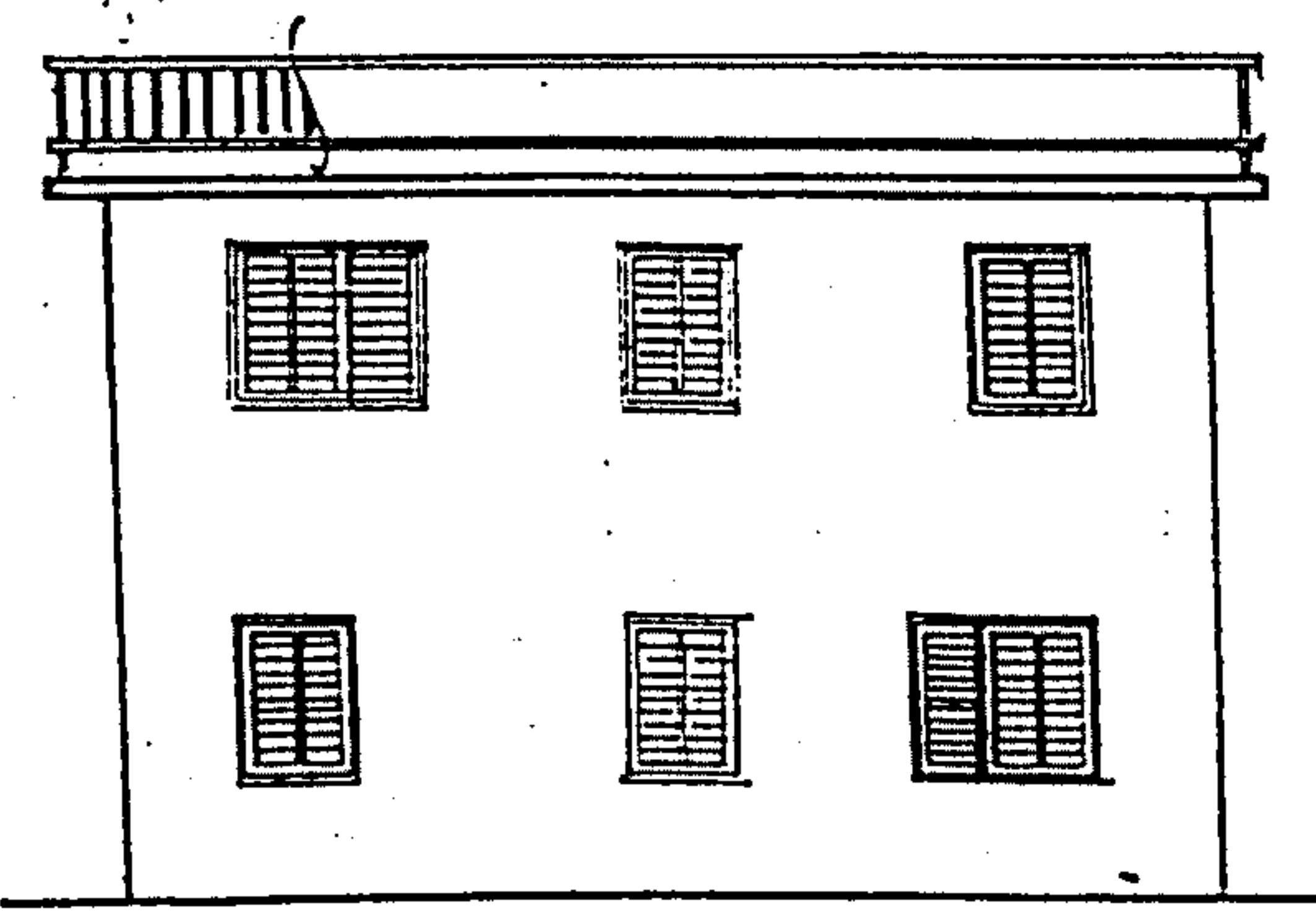
SOUTH ELEVATION



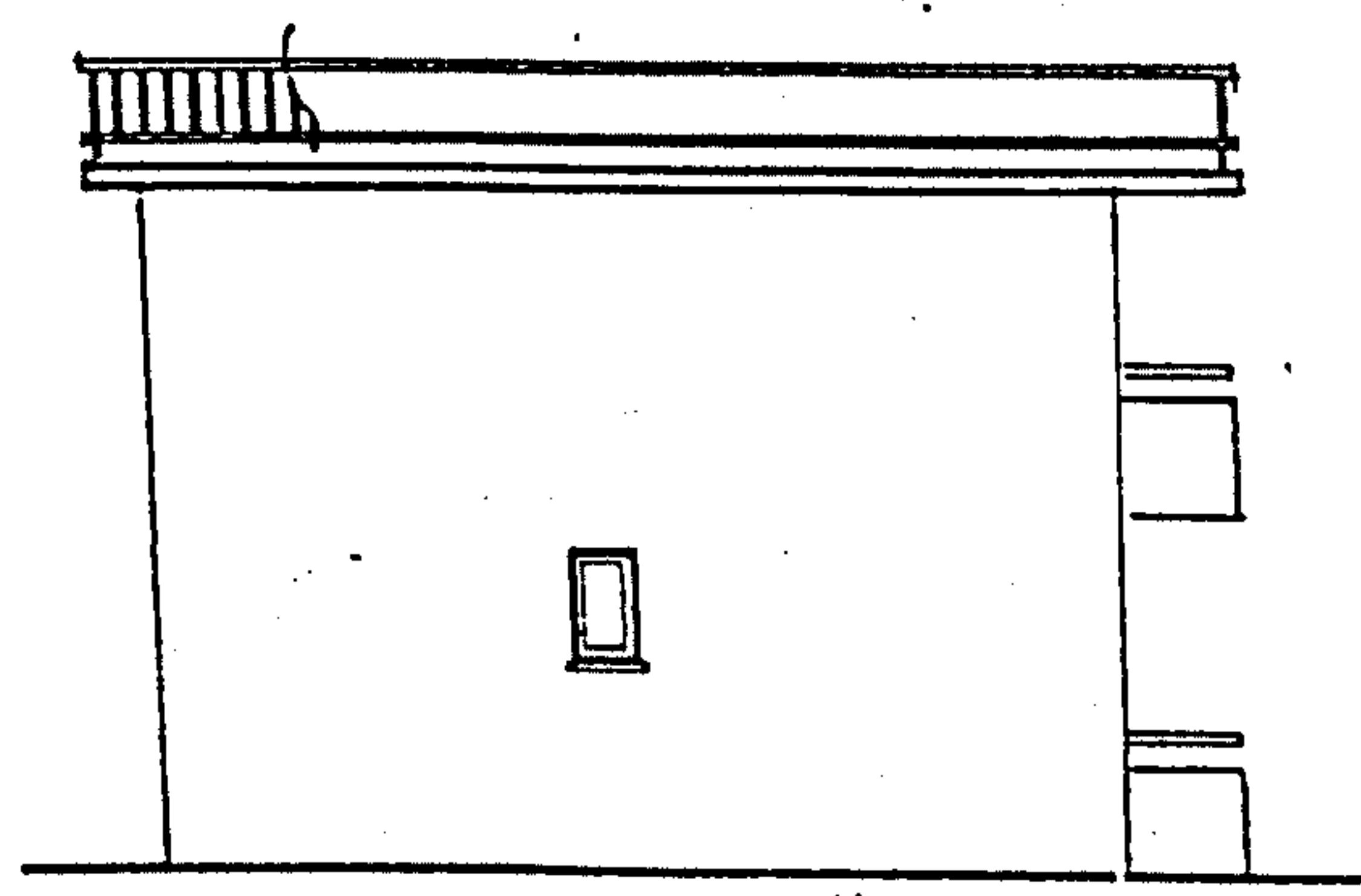
GROUND FLOOR



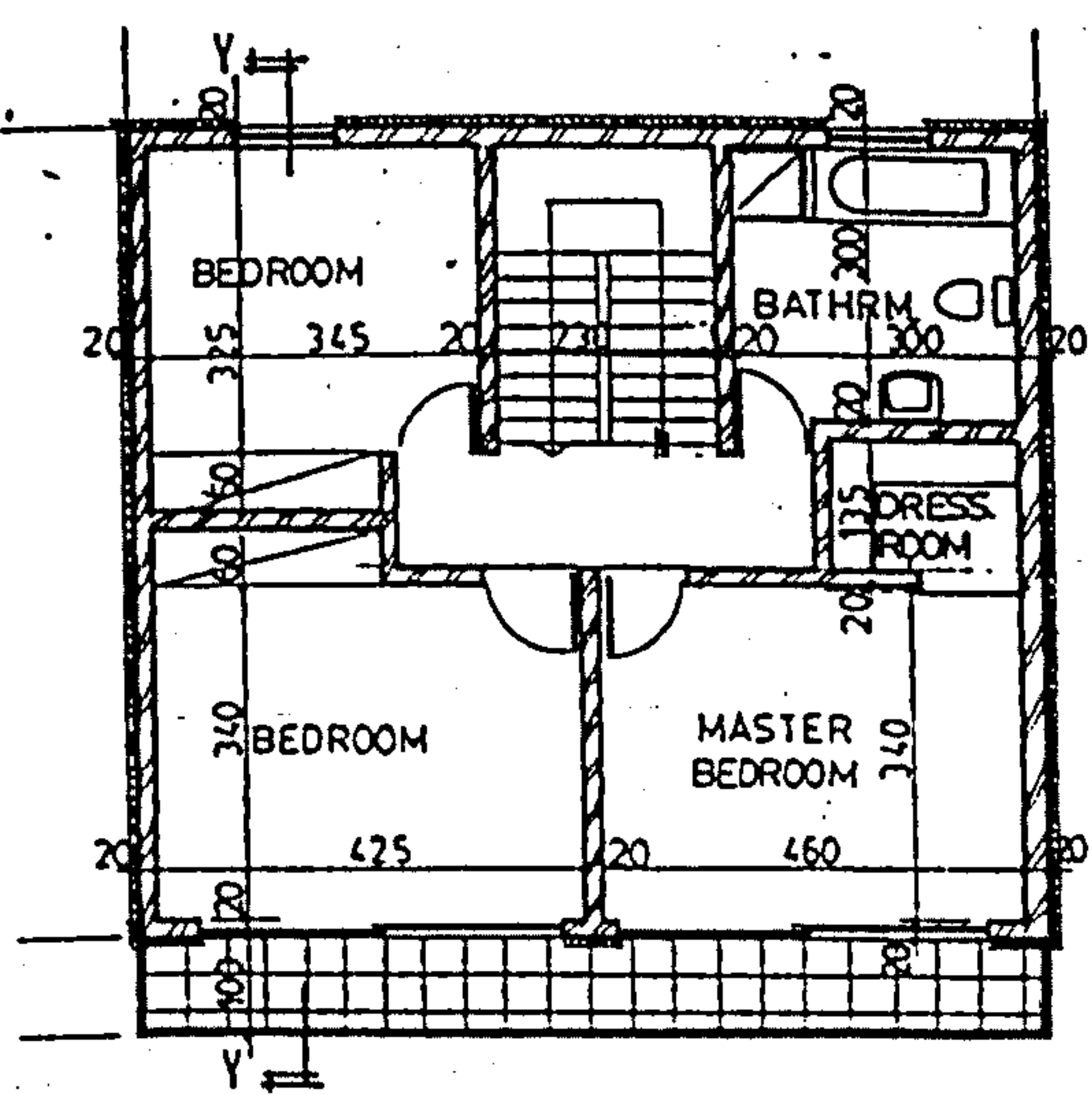
SECTION Y-Y



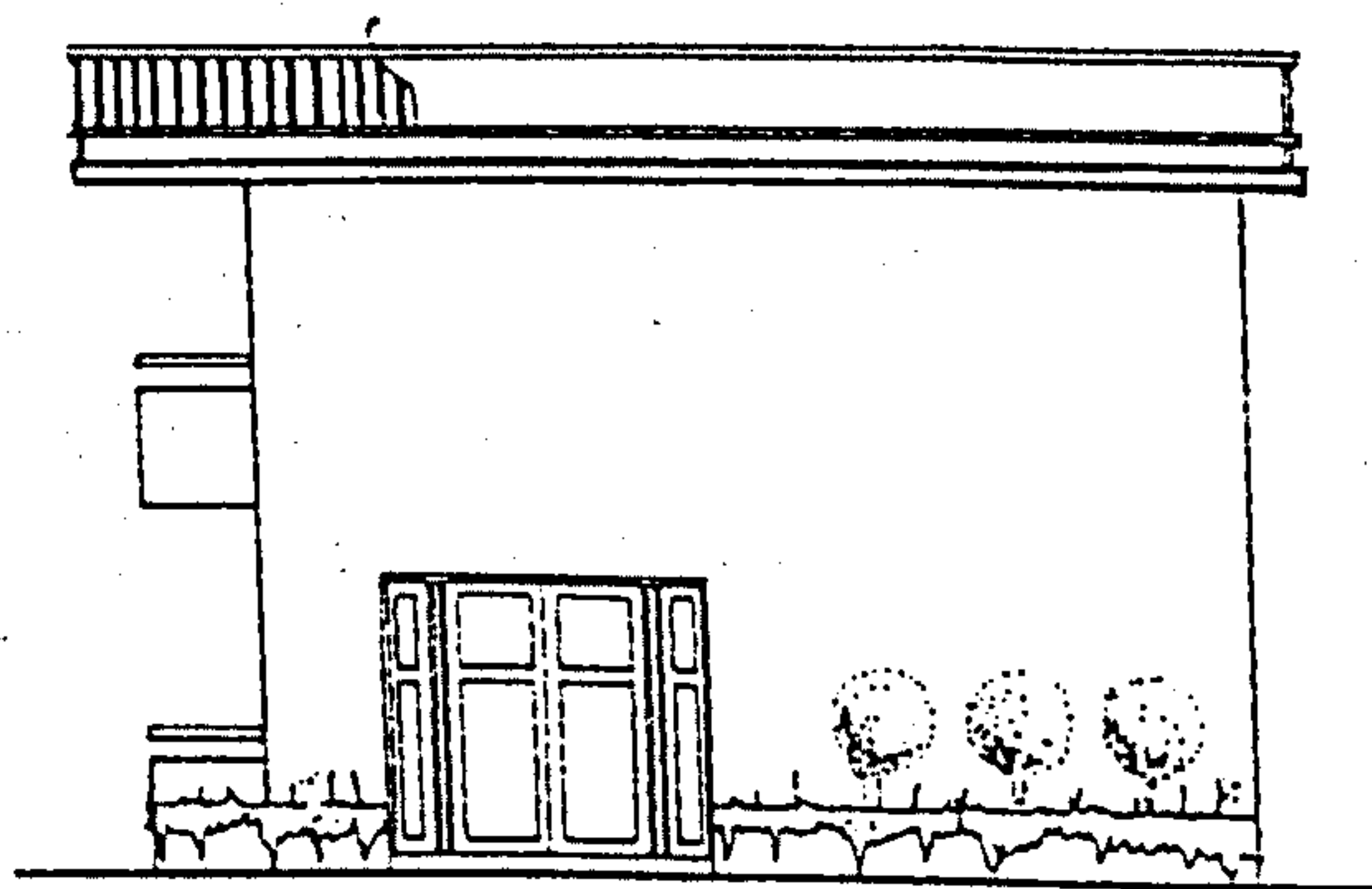
NORTH ELEVATION



WEST ELEVATION



FIRST FLOOR



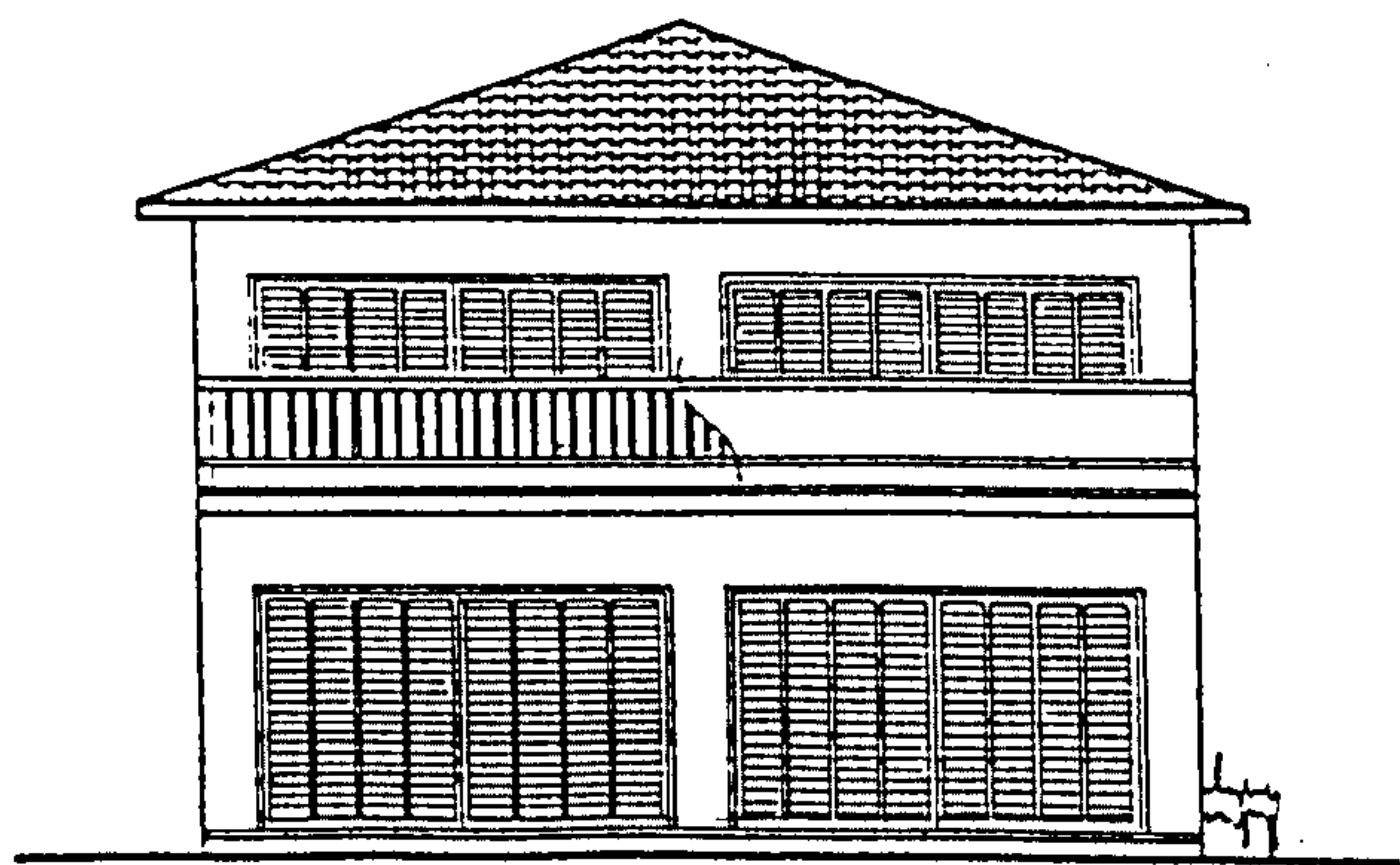
EAST ELEVATION



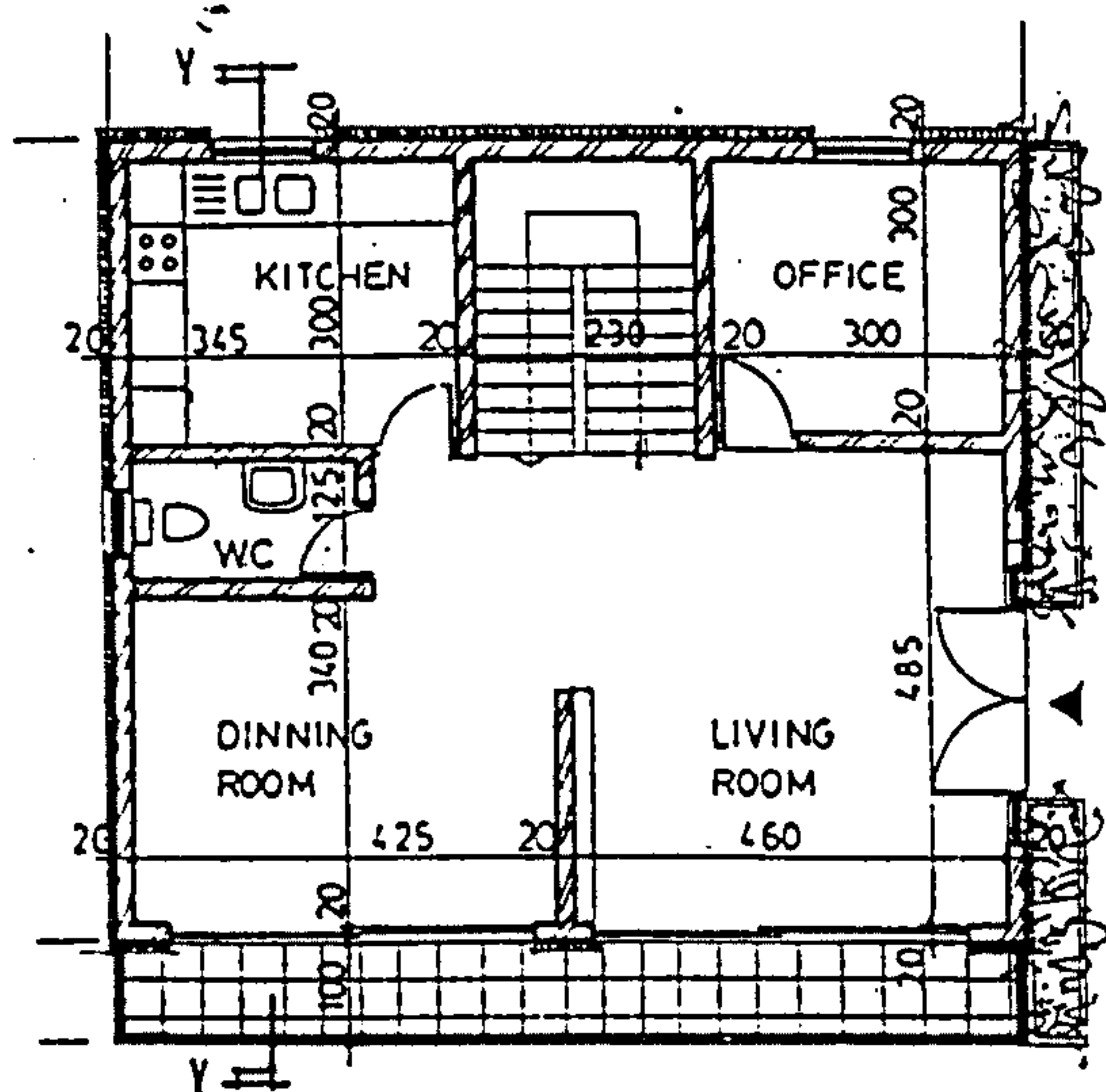
TEST NO:S18

DESIGN PARAMETER: MASS

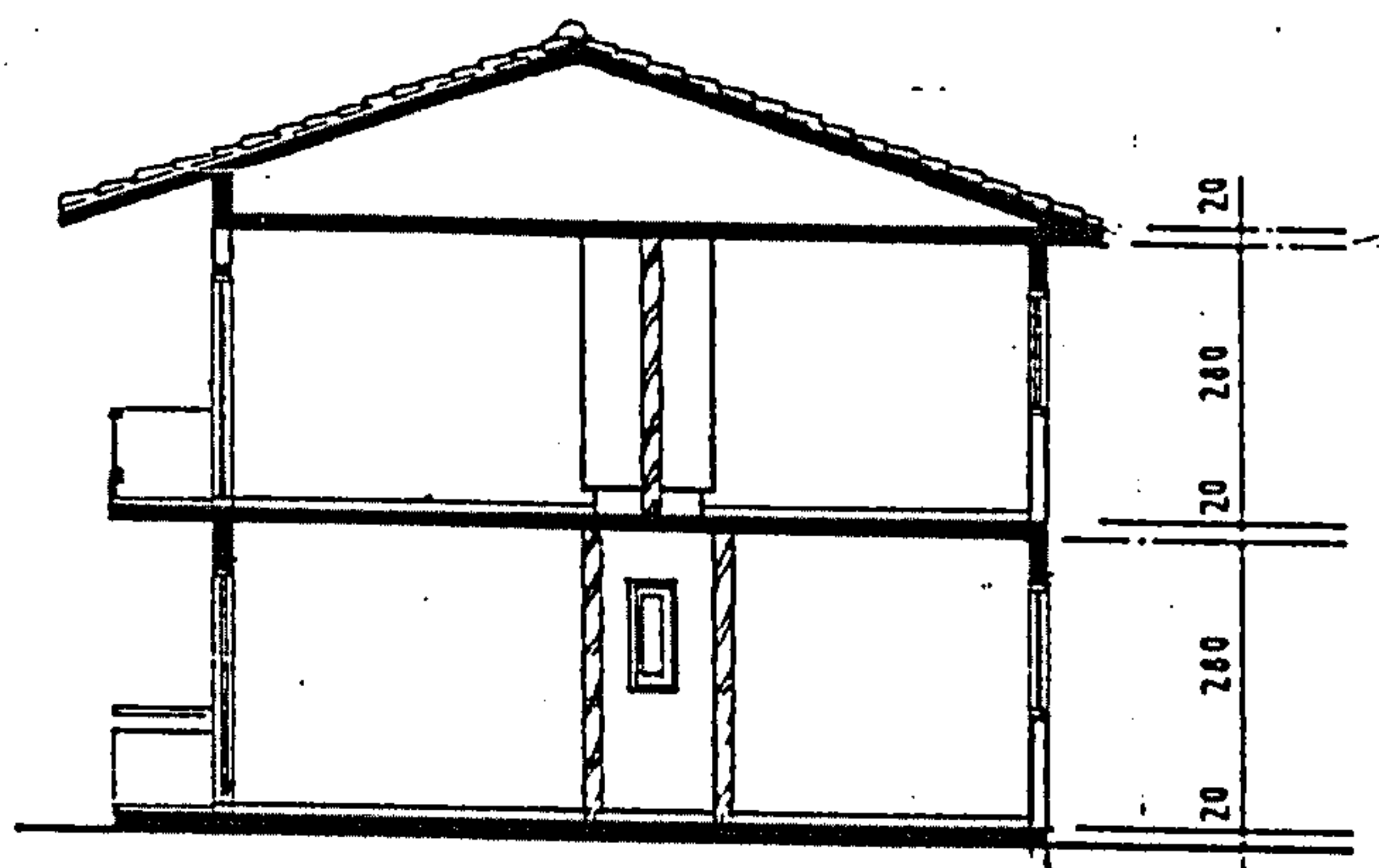
Adding roof tiles as Mass  
on S15



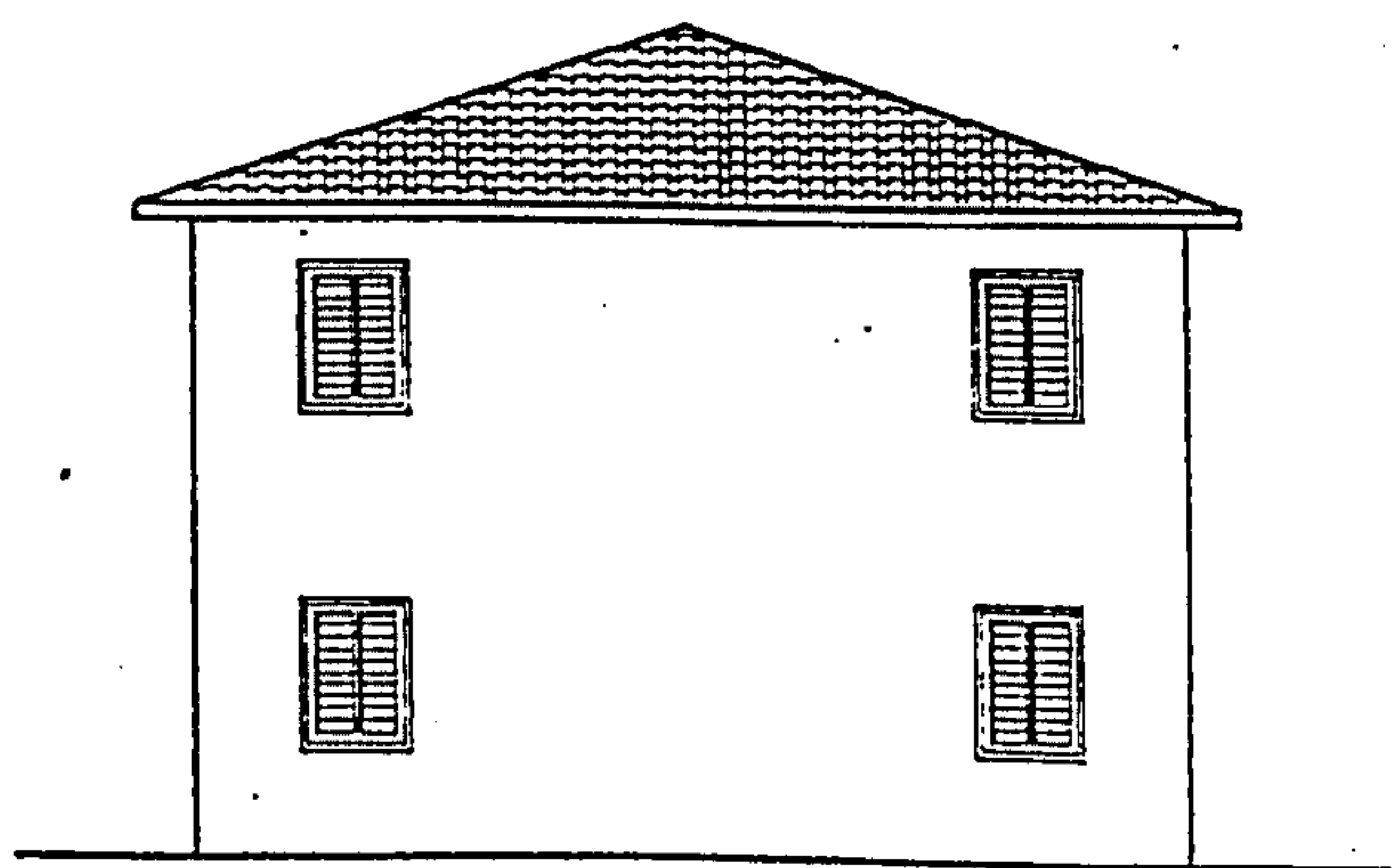
SOUTH ELEVATION



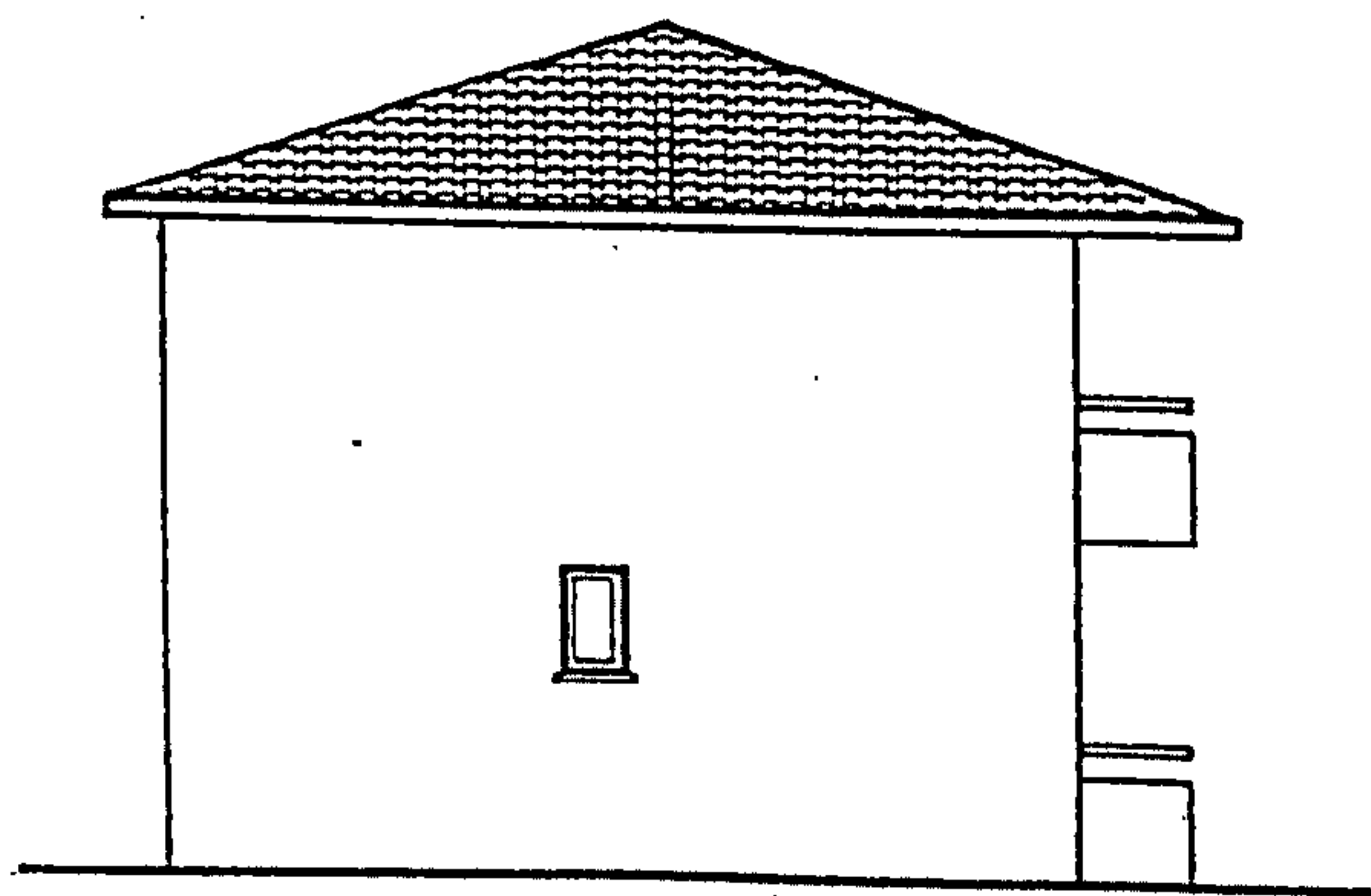
GROUND FLOOR



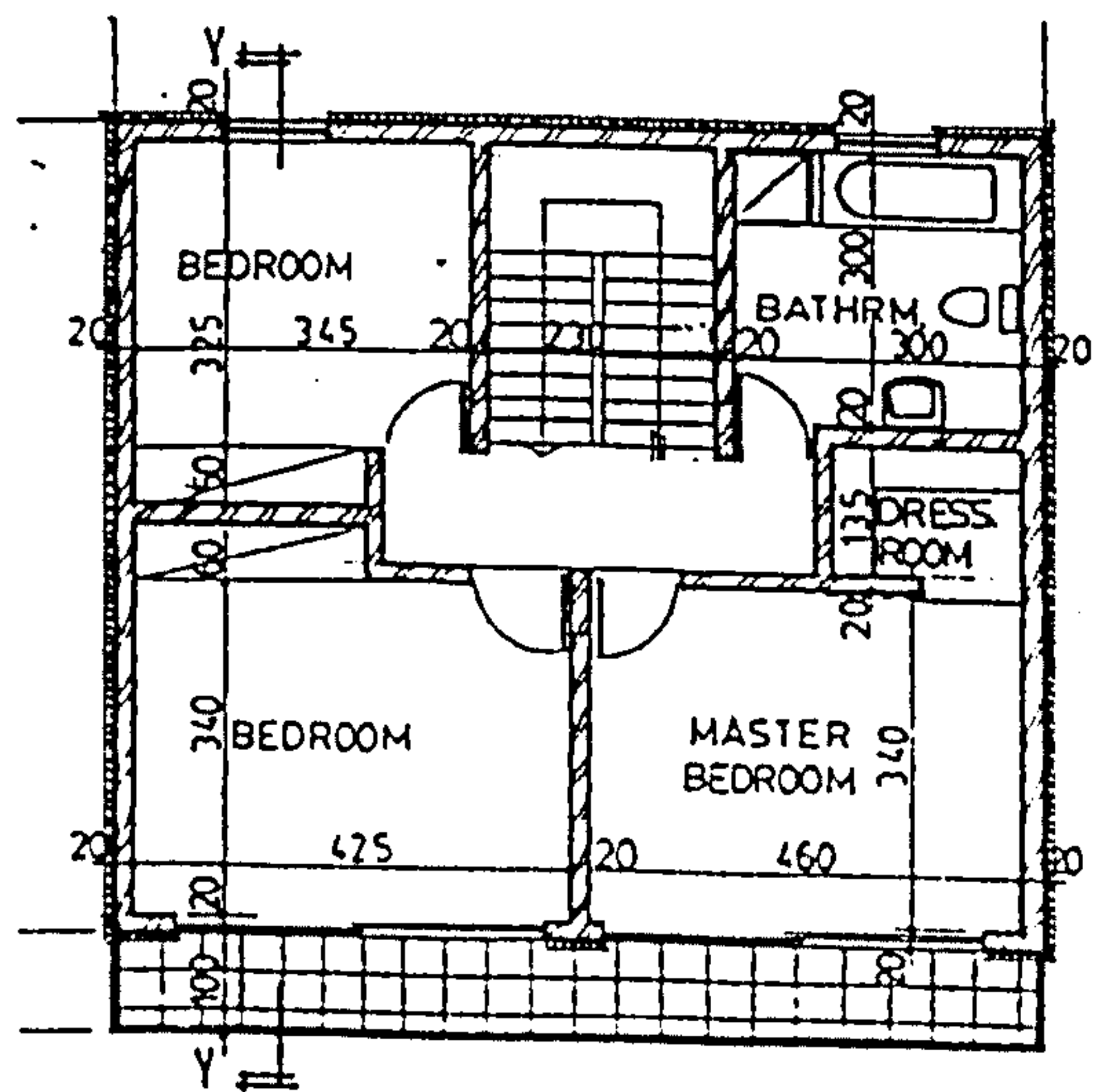
SECTION Y-Y



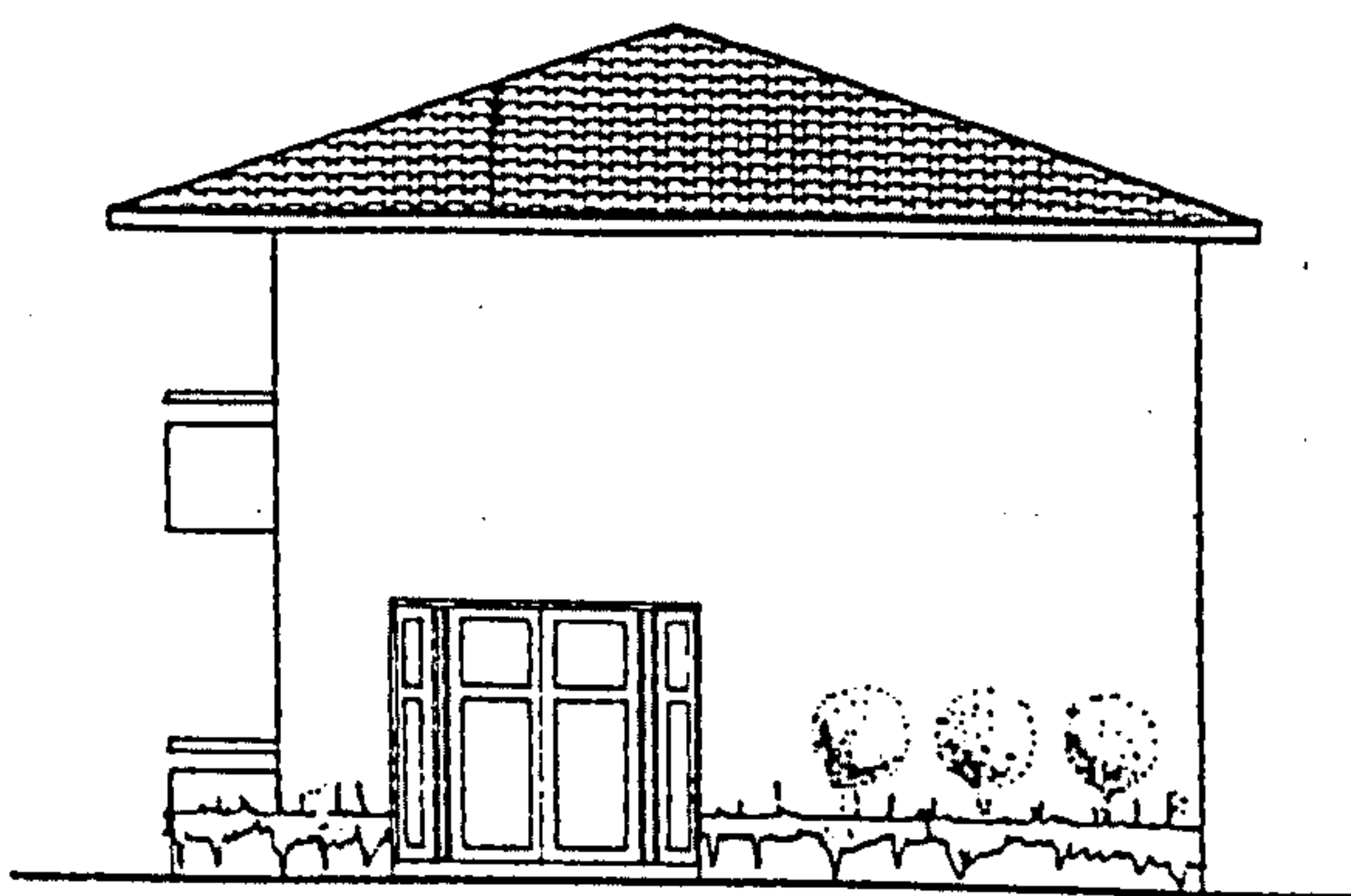
NORTH ELEVATION



WEST ELEVATION



FIRST FLOOR



EAST ELEVATION



## **APPENDIX 5.1.0**

### **SHADING - TABLES AND GRAPHS**



Table 5.1.0: OPTIMISED FENESTRATION WINTER SHADING STRATEGY

Winter\_Day - All windows Unshaded  
Summer\_Day - All windows Unshaded

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.7	19.4	13	35.1	13.8	26.1	20.5
2	23.0	7.0	24.4	19.2	14	35.4	14.1	26.3	20.6
3	22.6	6.8	24.1	19.1	15	34.4	13.5	26.5	20.6
4	22.3	6.7	23.8	18.9	16	33.4	12.7	26.6	20.5
5	22.0	6.5	23.5	18.8	17	31.9	11.5	26.6	20.4
6	23.1	6.5	25.0	18.7	18	30.0	10.5	26.6	20.2
7	25.9	6.6	25.1	18.8	19	27.8	9.7	26.6	20.1
8	28.6	7.4	25.2	19.1	20	26.1	9.0	26.6	20.0
9	30.5	10.0	25.4	19.4	21	25.2	8.5	26.5	19.9
10	32.2	11.8	25.5	19.7	22	24.3	8.0	26.5	19.7
11	33.6	12.9	25.7	20.0	23	24.1	7.6	25.3	19.6
12	34.7	13.6	25.9	20.3	24	23.8	7.3	25.1	19.4

Table 5.1.4: ALL FENESTRATION:-

Shaded on Winter and Summer Day

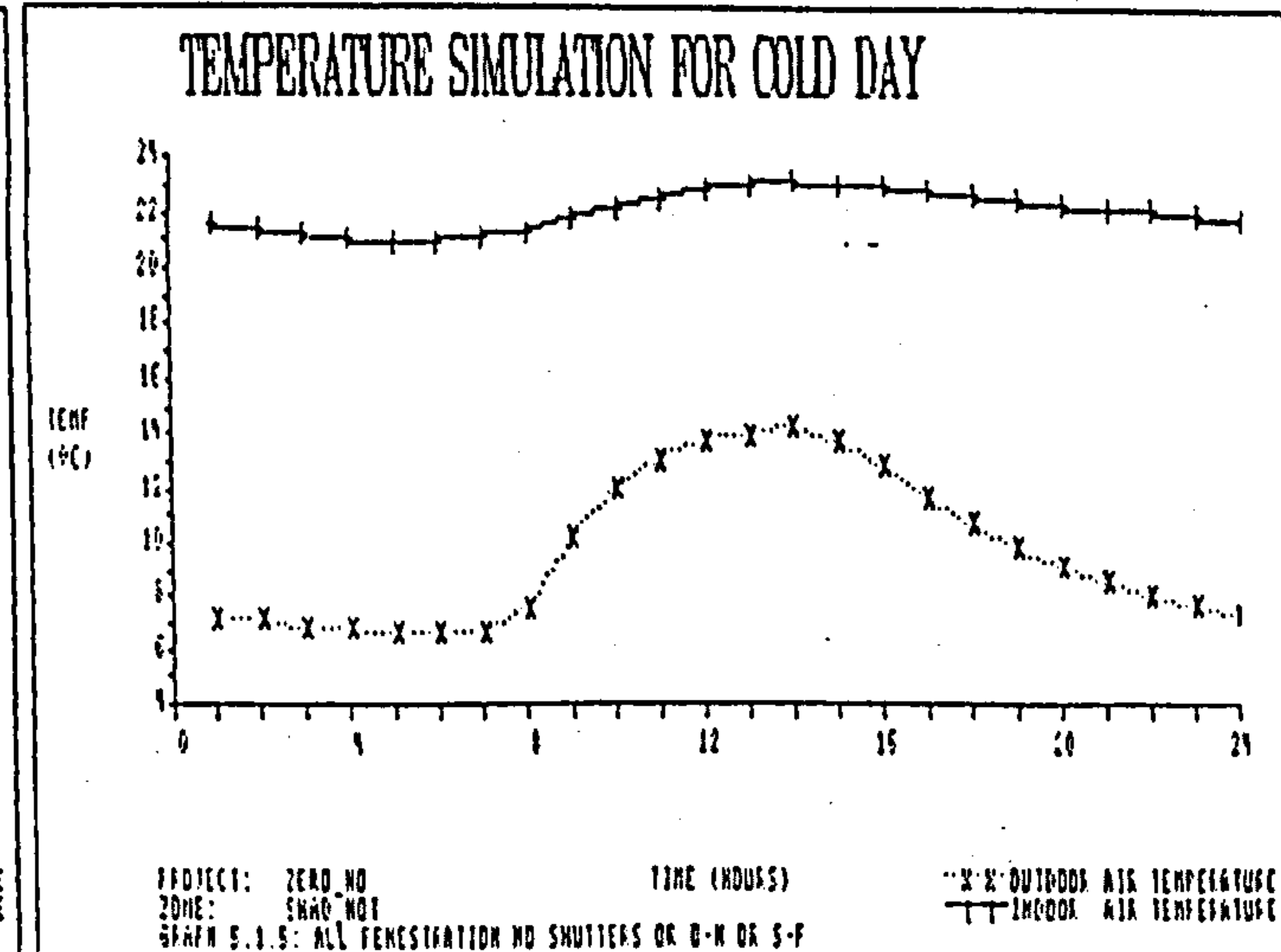
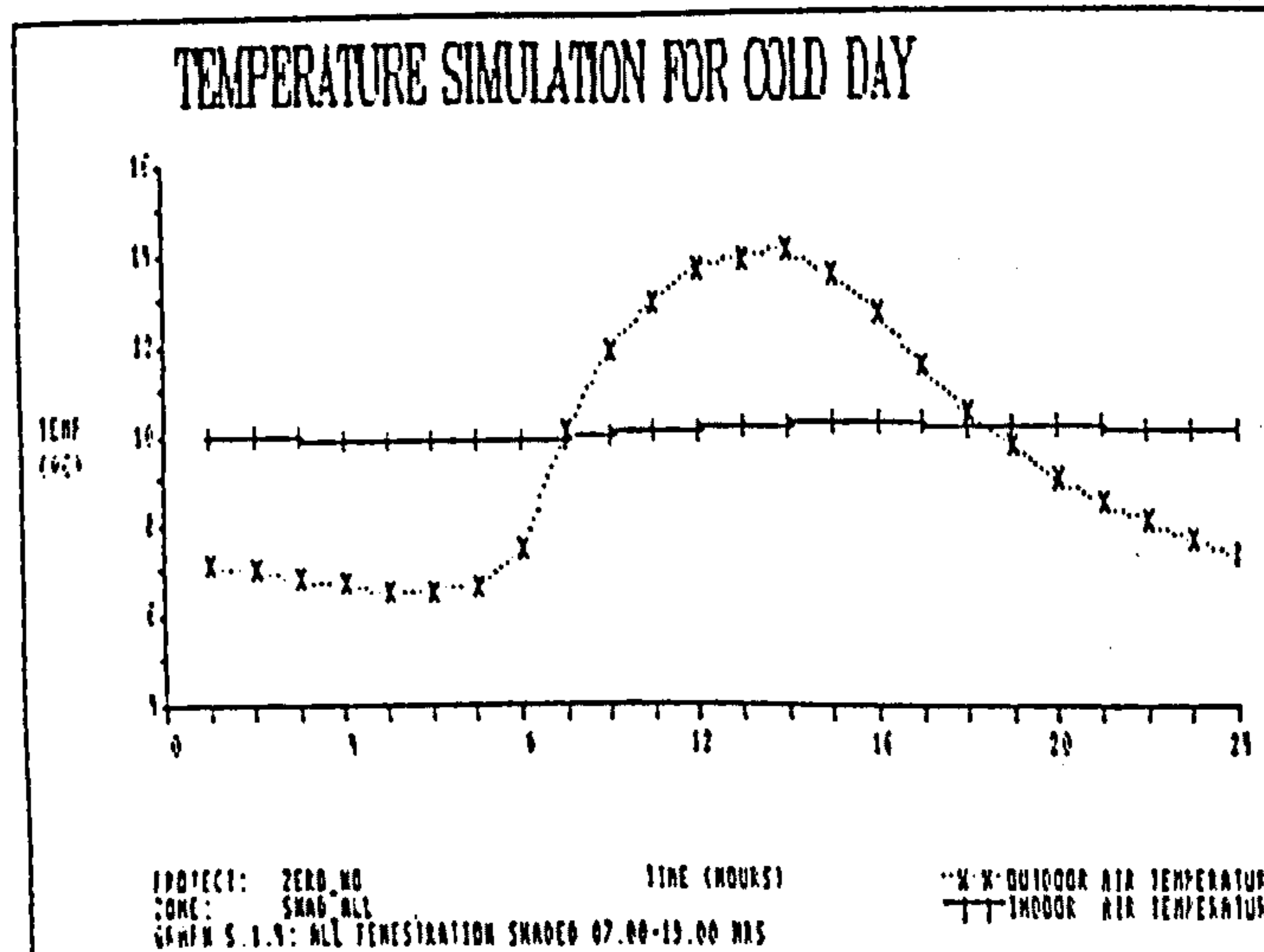
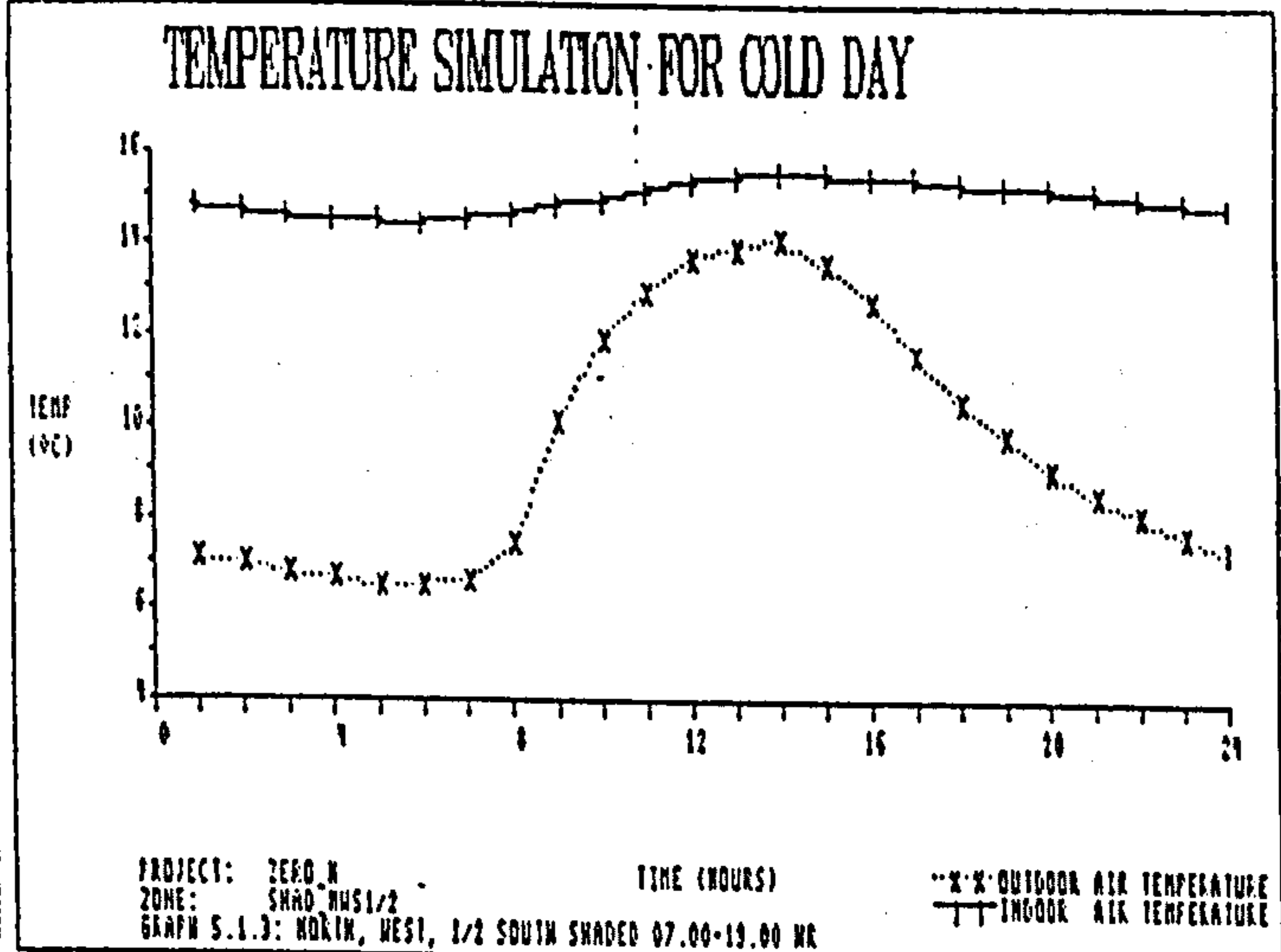
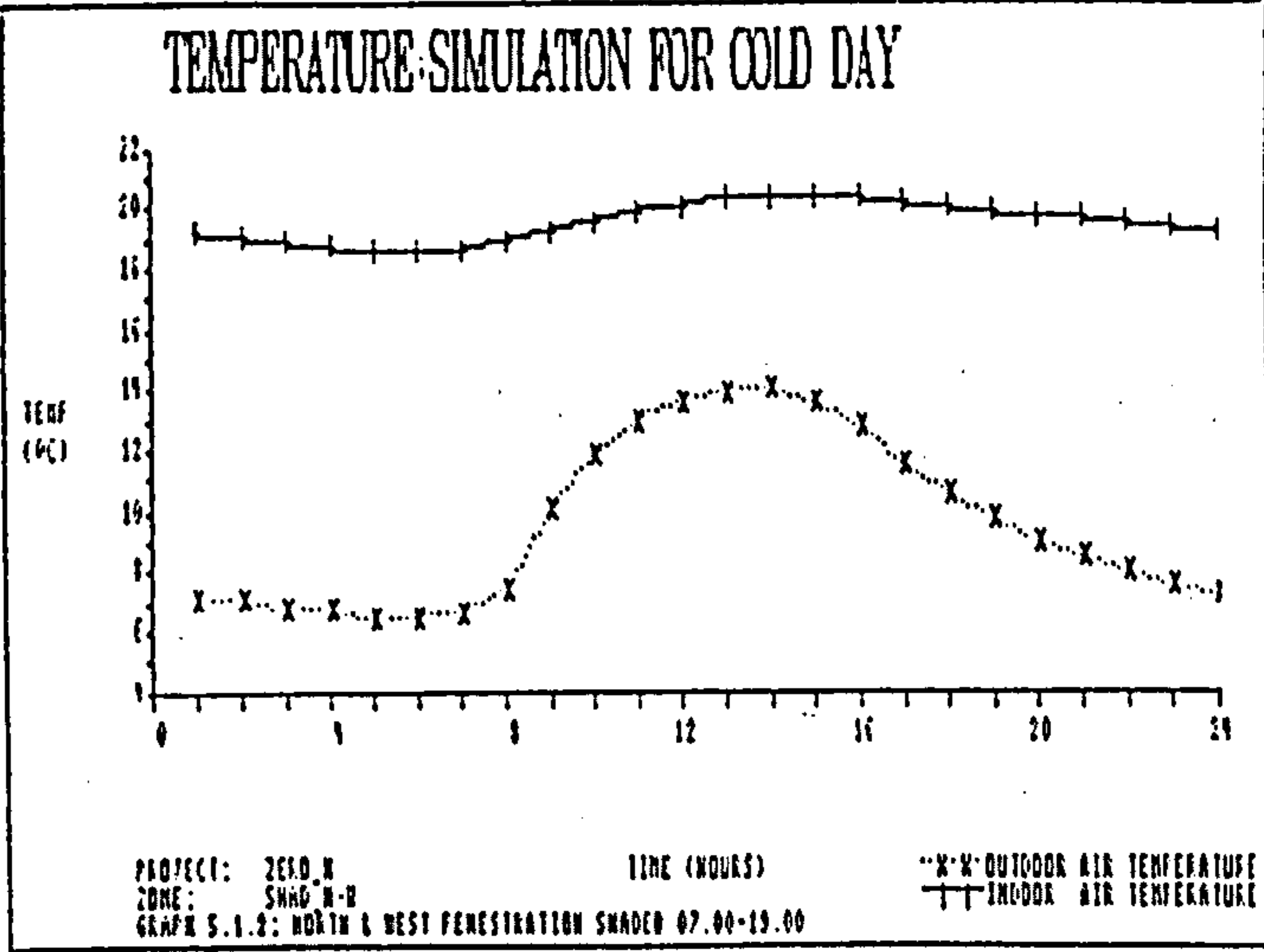
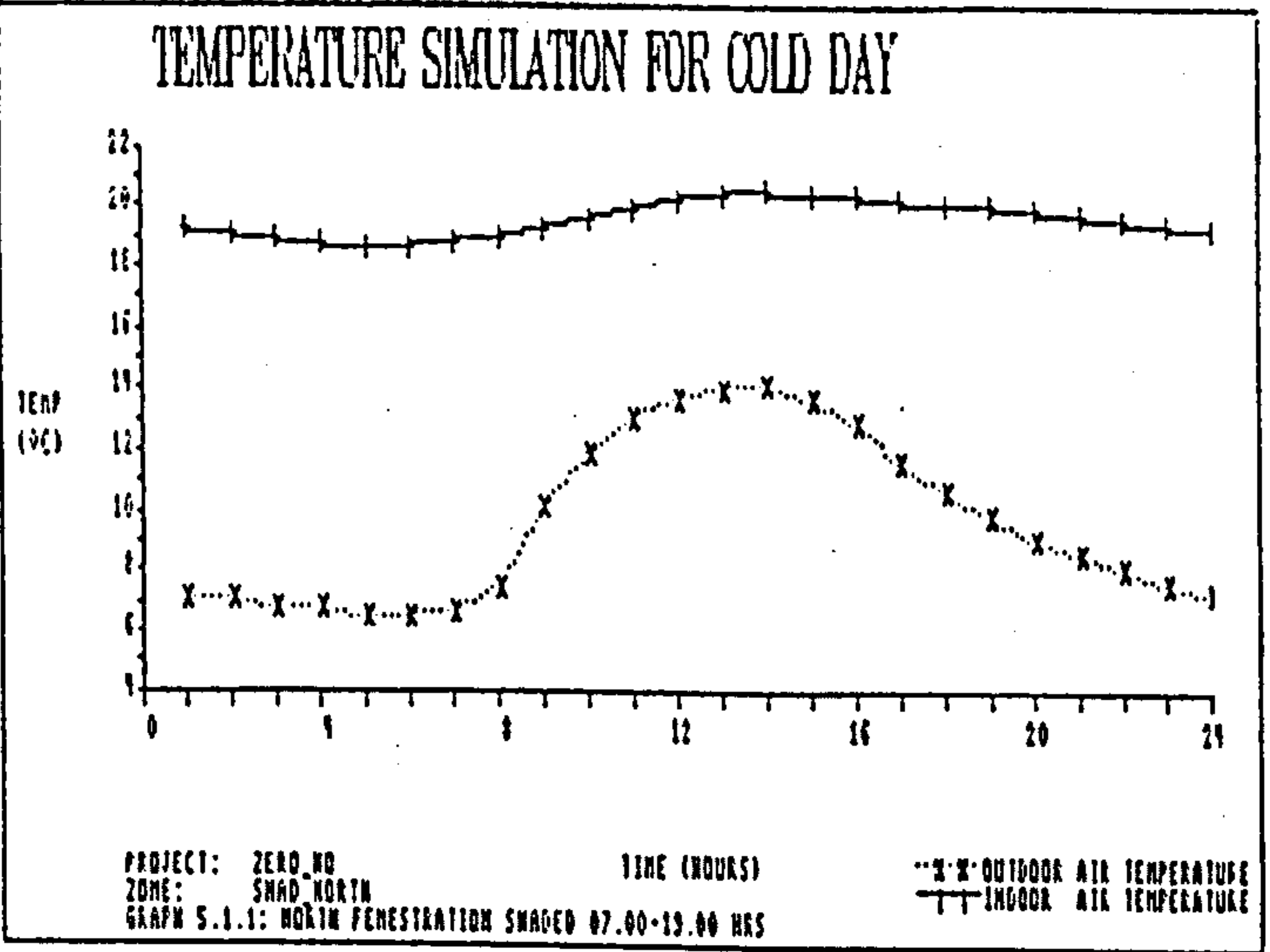
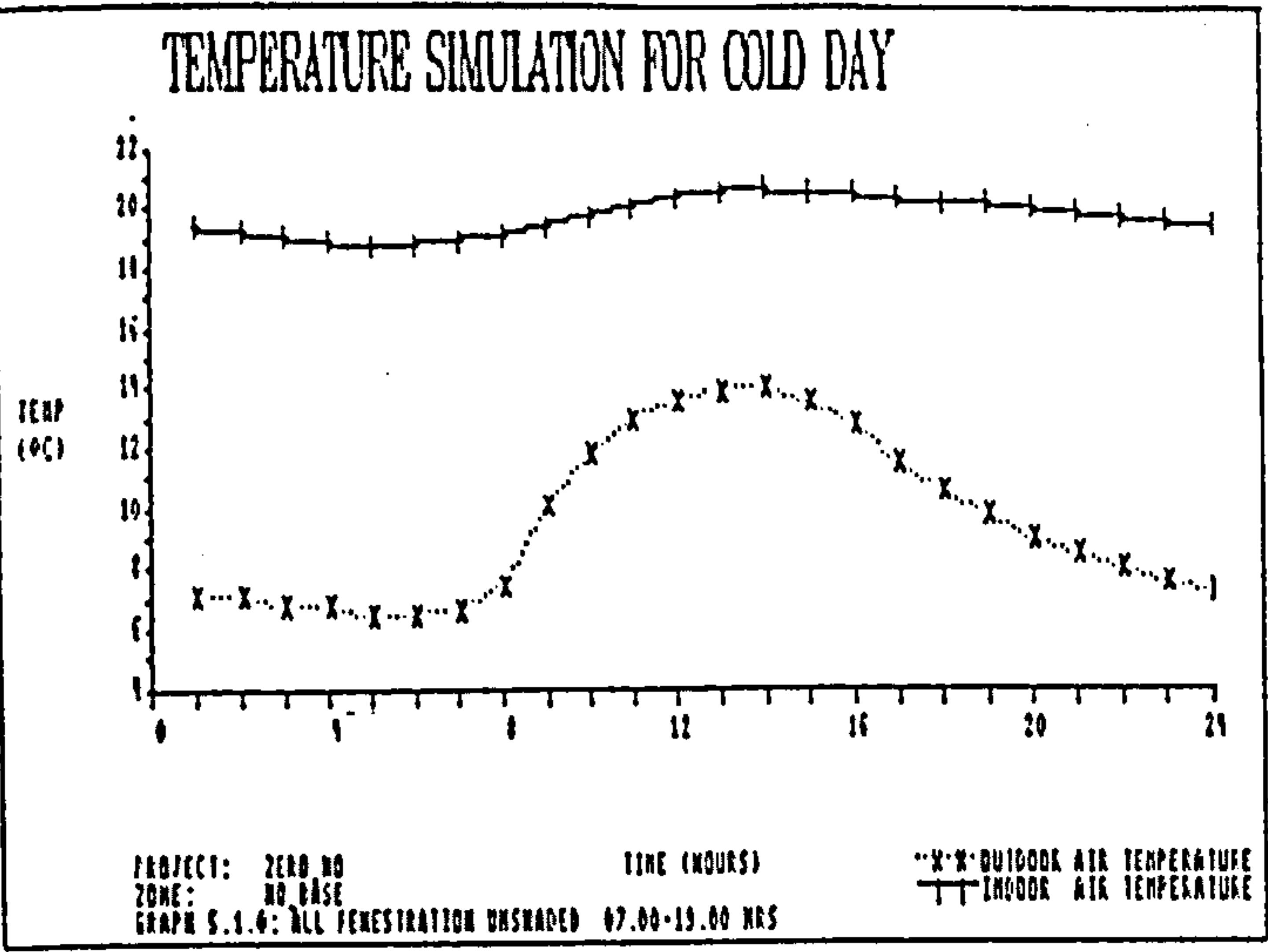
RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.2	10.0	13	35.1	13.8	25.1	10.1
2	23.0	7.0	24.0	10.0	14	35.4	14.1	25.2	10.2
3	22.6	6.8	23.7	9.9	15	34.4	13.5	25.3	10.2
4	22.3	6.7	23.5	9.9	16	33.4	12.7	25.4	10.2
5	22.0	6.5	23.3	9.8	17	31.9	11.5	25.4	10.2
6	23.1	6.5	24.3	9.8	18	30.0	10.5	25.4	10.2
7	25.9	6.6	24.4	9.8	19	27.8	9.7	25.4	10.2
8	28.6	7.4	24.4	9.8	20	26.1	9.0	25.4	10.2
9	30.5	10.0	24.6	9.9	21	25.2	8.5	25.4	10.1
10	32.2	11.8	24.7	9.9	22	24.3	8.0	25.3	10.1
11	33.6	12.9	24.8	10.0	23	24.1	7.6	24.8	10.1
12	34.7	13.6	24.9	10.1	24	23.8	7.3	24.6	10.0

Table 5.1.5: ALL FENESTRATION:-

NO Overhangs and Vertical Fins  
NO Shutters

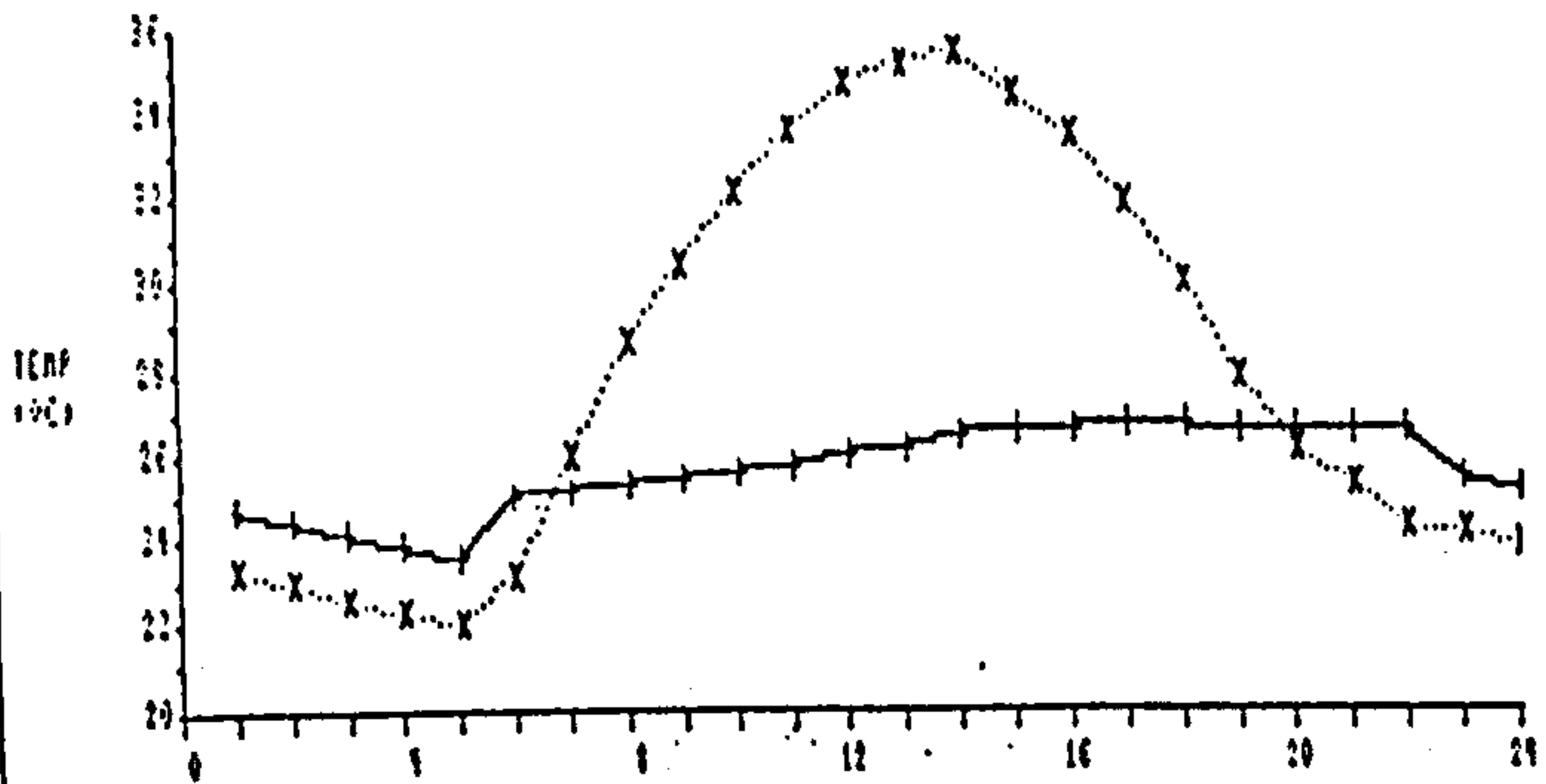
RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	25.0	21.5	13	35.1	13.8	27.0	22.9
2	23.0	7.0	24.7	21.3	14	35.4	14.1	27.2	23.0
3	22.6	6.8	24.3	21.2	15	34.4	13.5	27.3	22.9
4	22.3	6.7	24.0	21.0	16	33.4	12.7	27.4	22.8
5	22.0	6.5	23.8	20.8	17	31.9	11.5	27.5	22.7
6	23.1	6.5	25.4	20.7	18	30.0	10.5	27.5	22.5
7	25.9	6.6	25.5	20.9	19	27.8	9.7	27.4	22.4
8	28.6	7.4	25.7	21.2	20	26.1	9.0	27.4	22.2
9	30.5	10.0	25.9	21.6	21	25.2	8.5	27.4	22.1
10	32.2	11.8	26.2	22.0	22	24.3	8.0	27.3	21.9
11	33.6	12.9	26.5	22.3	23	24.1	7.6	25.7	21.7
12	34.7	13.6	26.7	22.7	24	23.8	7.3	25.4	21.6







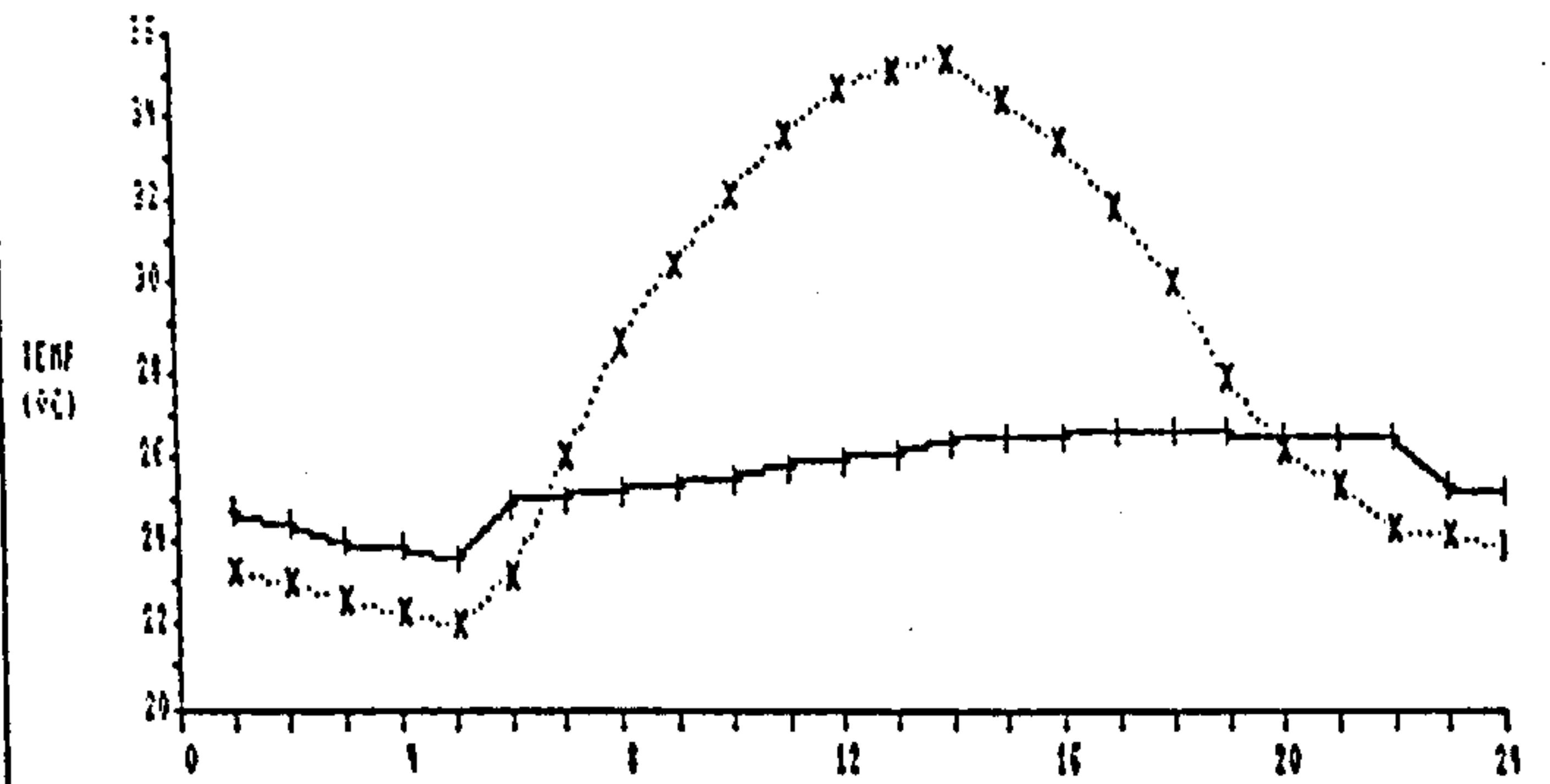
### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: HQ BASE  
GRAPH 5.1.1: ALL FENESTRATION UNSHADED 07.00-19.00 HRS

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE

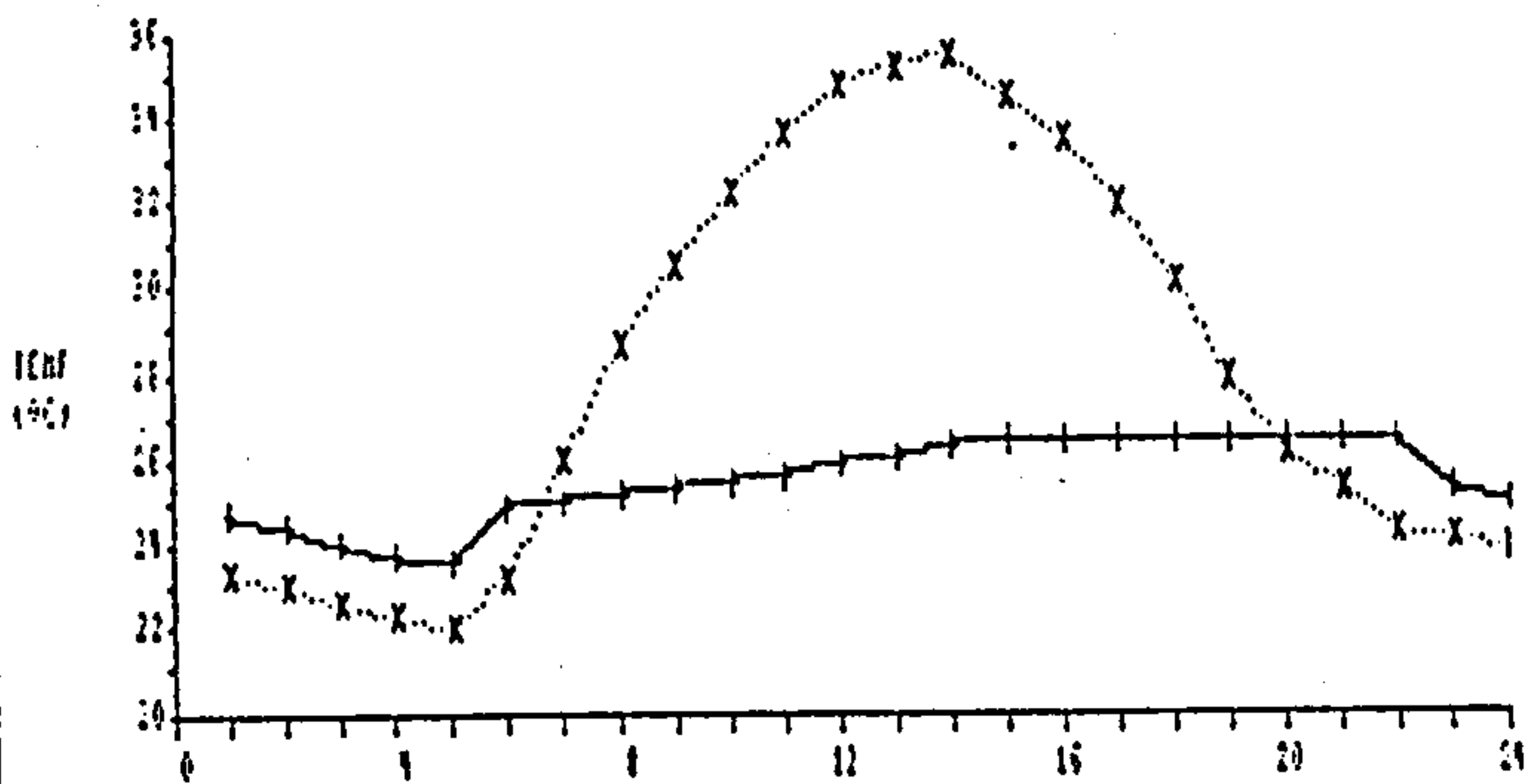
### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: SHAD NORTH  
GRAPH 5.1.2: NORTH FENESTRATION SHADED 07.00-19.00 HRS

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE

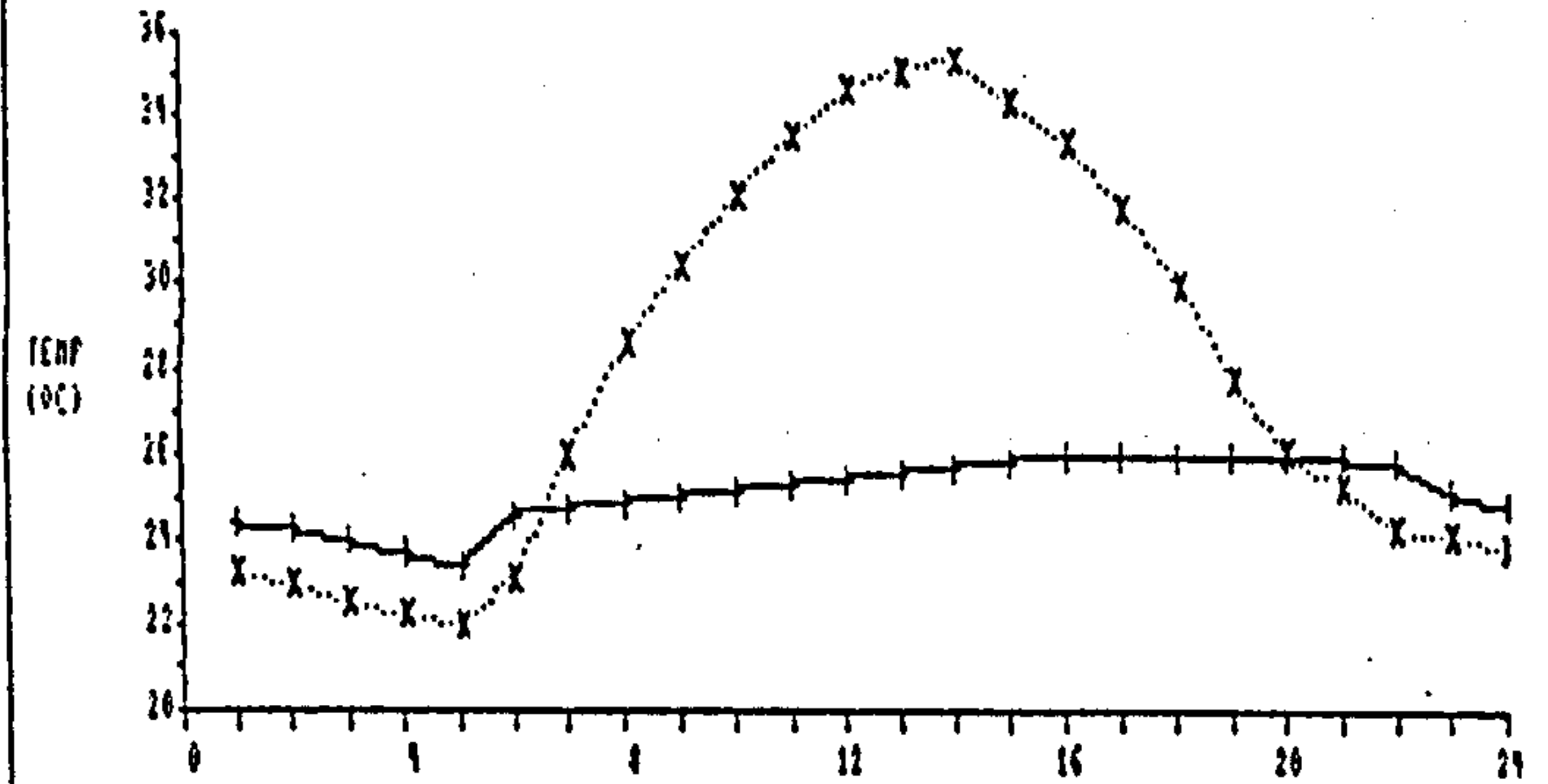
### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: SHAD N-W  
GRAPH 5.1.3: NORTH & WEST FENESTRATION SHADED 07.00-19.00

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE

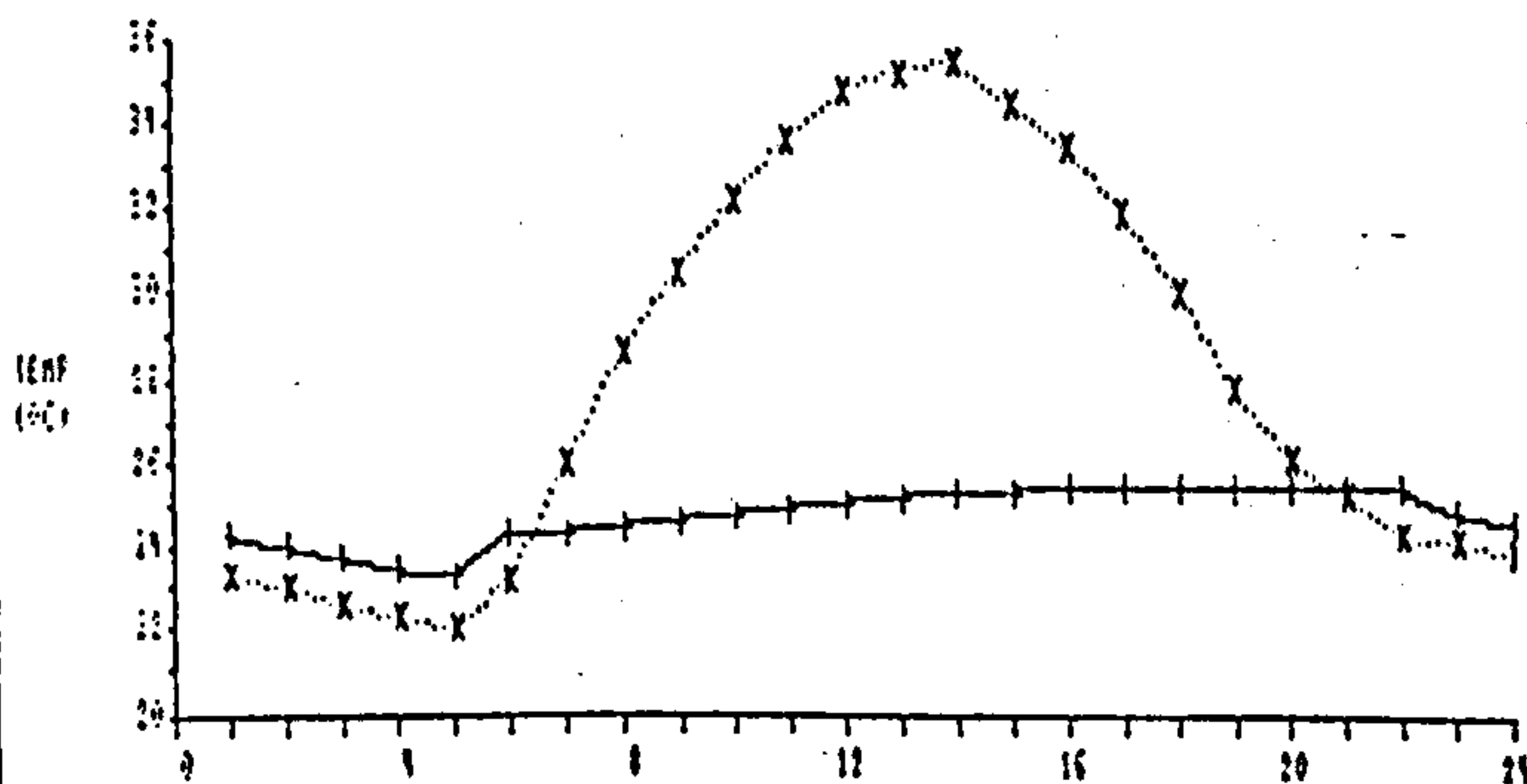
### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: SHAD NW 1/2 S  
GRAPH 5.1.4: NORTH, WEST, 1/2 SOUTH SHADED 07.00-19.00 HRS

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE

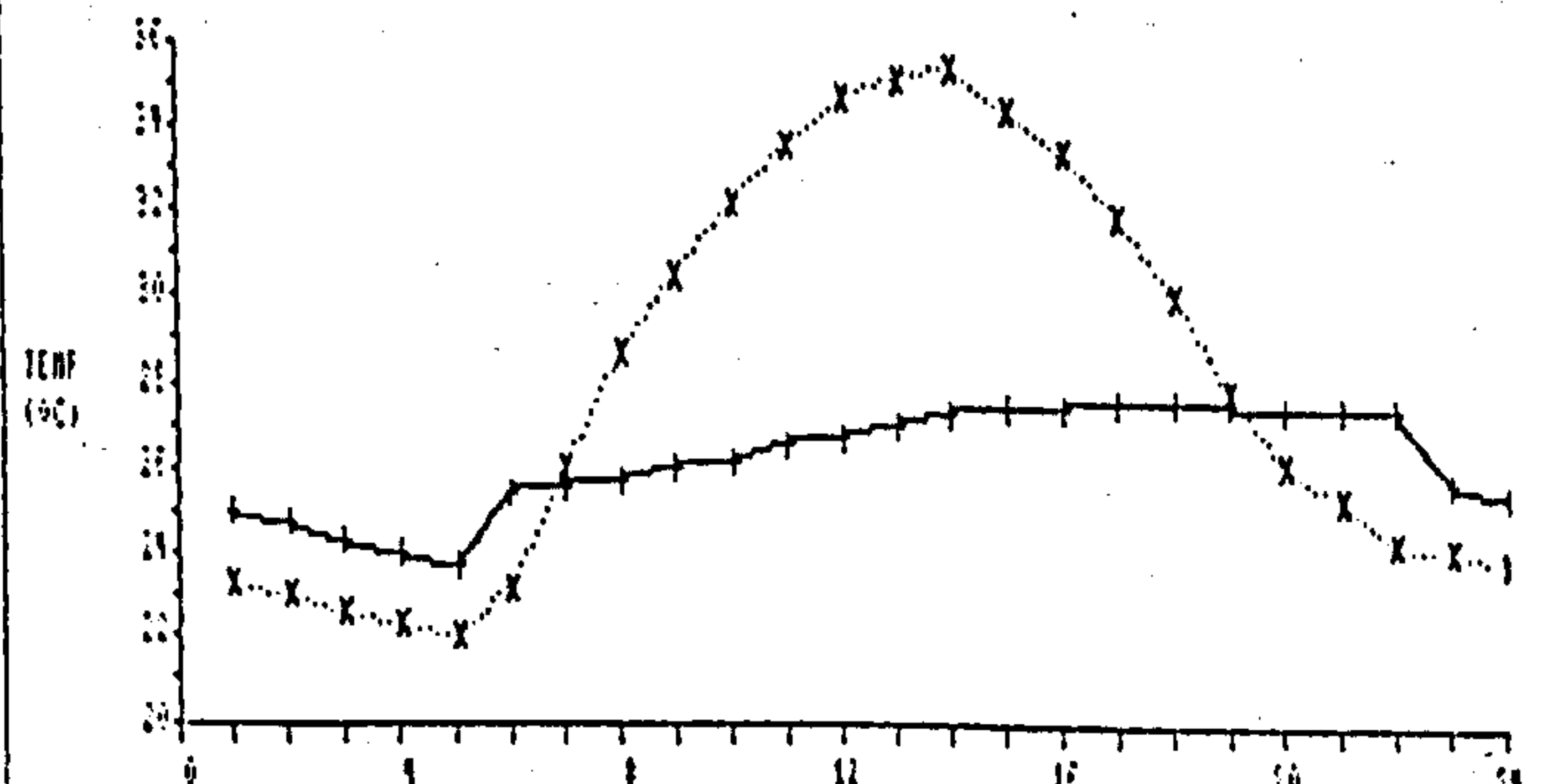
### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: SHAD ALL  
GRAPH 5.1.5: ALL FENESTRATION SHADED 07.00-19.00 HRS

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
ZONE: SHAD HQ  
GRAPH 5.1.6: ALL FENESTRATION NO SHUTTERS ON O-W OR S-F

--X--X-- OUTDOOR AIR TEMPERATURE  
+ + + INDOOR AIR TEMPERATURE



## **APPENDIX 5.2.0**

### **VENTILATION - TABLES AND GRAPHS**



5.2.1.0 Optimized Ventilation Strategy for Summer Nights  
All Windows open - 40.0m2

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.6	18.7	13	35.1	13.5	26.1	19.8
2	23.0	7.0	24.3	18.5	14	35.4	14.1	26.3	19.9
3	22.6	6.8	24.0	18.4	15	34.4	13.5	26.5	19.9
4	22.3	6.7	23.7	18.3	16	33.4	12.7	26.6	19.8
5	22.0	6.5	23.4	18.1	17	31.9	11.5	26.6	19.7
6	23.1	6.5	24.9	18.1	18	30.0	10.5	26.6	19.5
7	25.9	6.6	25.0	18.2	19	27.8	9.7	26.6	19.4
8	28.6	7.4	25.2	18.4	20	26.1	9.0	26.6	19.3
9	30.5	10.0	25.3	18.7	21	25.2	8.5	26.5	19.2
10	32.2	11.8	25.5	19.0	22	24.3	8.0	26.5	19.0
11	33.6	12.9	25.7	19.3	23	24.1	7.6	25.3	18.9
12	34.7	13.6	25.9	19.6	24	23.8	7.3	25.0	18.8

Table 5.2.1.8: 40.0m2 Closed Window Area  
All Windows closed

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	31.7	19.5	13	35.1	13.8	32.1	20.6
2	23.0	7.0	31.6	19.3	14	35.4	14.1	32.2	20.7
3	22.6	6.8	31.5	19.2	15	34.4	13.5	32.3	20.7
4	22.3	6.7	31.4	19.0	16	33.4	12.7	32.4	20.6
5	22.0	6.5	31.3	18.9	17	31.9	11.5	32.3	20.5
6	23.1	6.5	31.3	18.8	18	30.0	10.5	32.3	20.3
7	25.9	6.6	31.4	18.9	19	27.8	9.7	32.2	20.2
8	28.6	7.4	31.5	19.2	20	26.1	9.0	32.1	20.1
9	30.5	10.0	31.6	19.5	21	25.2	8.5	32.0	19.9
10	32.2	11.8	31.7	19.8	22	24.3	8.0	31.9	19.8
11	33.6	12.9	31.8	20.1	23	24.1	7.6	31.8	19.7
12	34.7	13.6	31.9	20.4	24	23.8	7.3	31.8	19.5

Table 5.2.1.10: 2.0m2 Open Window Area at 1M and 5M Height  
Between 00.00 - 24.00 Hours

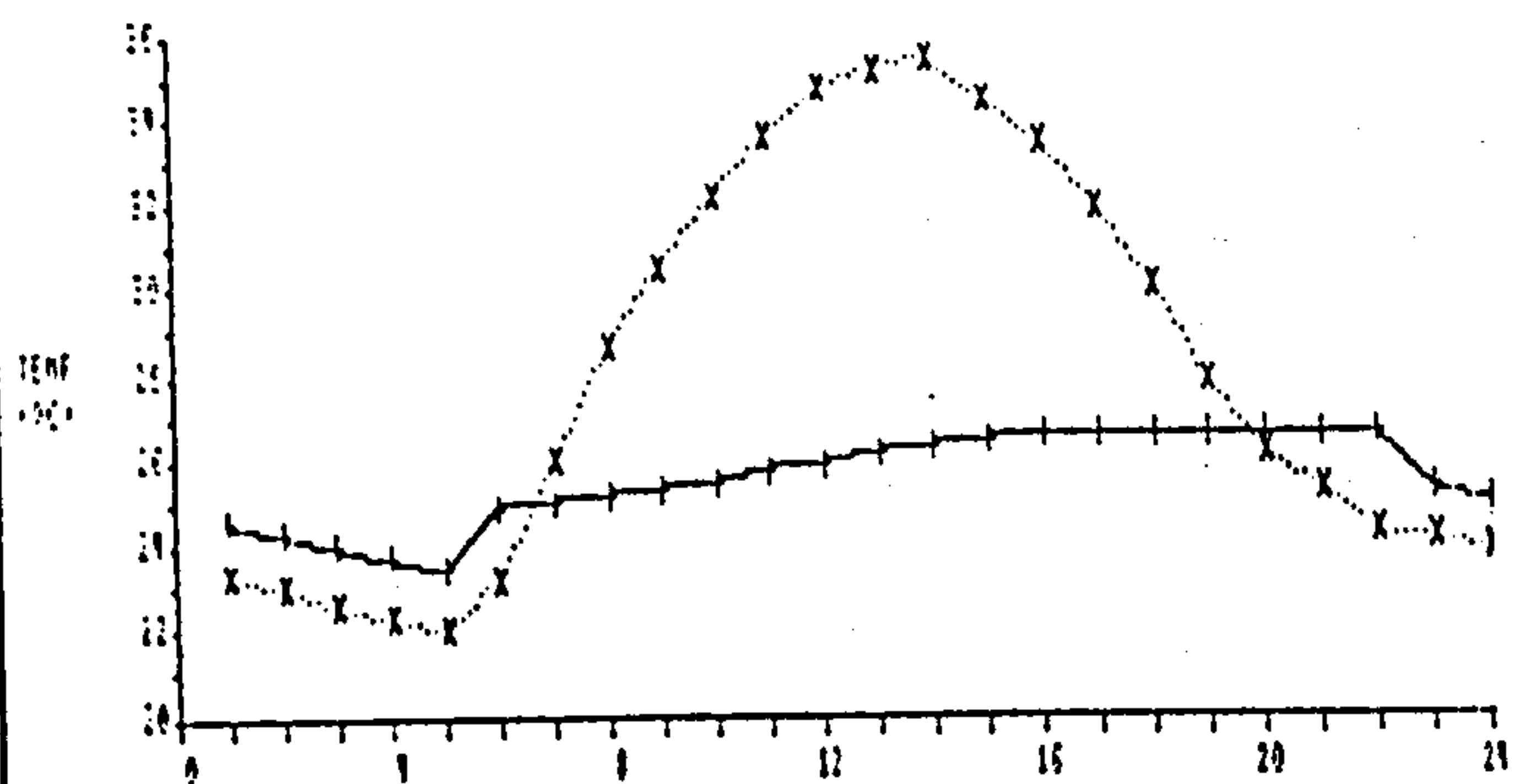
RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	28.7	18.6	13	35.1	13.8	30.0	19.5
2	23.0	7.0	28.6	18.5	14	35.4	14.1	30.2	19.6
3	22.6	6.8	28.4	18.4	15	34.4	13.5	30.3	19.6
4	22.3	6.7	28.2	18.3	16	33.4	12.7	30.3	19.5
5	22.0	6.5	28.1	18.2	17	31.9	11.5	30.2	19.4
6	23.1	6.5	28.2	18.1	18	30.0	10.5	30.0	19.3
7	25.9	6.6	28.5	18.2	19	27.8	9.7	29.9	19.2
8	28.6	7.4	28.7	18.4	20	26.1	9.0	29.6	19.1
9	30.5	10.0	28.9	18.6	21	25.2	8.5	29.4	19.0
10	32.2	11.8	29.2	18.9	22	24.3	8.0	29.2	18.9
11	33.6	12.9	29.5	19.1	23	24.1	7.6	29.1	18.8
12	34.7	13.6	29.8	19.3	24	23.8	7.3	28.9	18.7

Table 5.2.1.12: 38.0m2 Closed Window Area (22.00 - 06.00 Hours)  
2.0m2 Open Window Area at 1M and 5M Height  
Between 06.00 - 22.00 Hours

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]									
Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	31.3	16.8	13	35.1	13.8	31.7	17.6
2	23.0	7.0	31.2	16.7	14	35.4	14.1	31.8	17.7
3	22.6	6.8	31.1	16.6	15	34.4	13.5	31.9	17.8
4	22.3	6.7	31.0	16.4	16	33.4	12.7	32.0	17.8
5	22.0	6.5	31.0	16.3	17	31.9	11.5	32.0	17.7
6	23.1	6.5	30.9	15.8	18	30.0	10.5	31.9	17.6
7	25.9	6.6	31.0	15.9	19	27.8	9.7	31.9	17.5
8	28.6	7.4	31.1	16.1	20	26.1	9.0	31.8	17.4
9	30.5	10.0	31.2	16.5	21	25.2	8.5	31.7	17.2
10	32.2	11.8	31.3	16.8	22	24.3	8.0	30.8	17.1
11	33.6	12.9	31.4	17.2	23	24.1	7.6	31.4	17.0
12	34.7	13.6	31.5	17.4	24	23.8	7.3	31.3	16.9

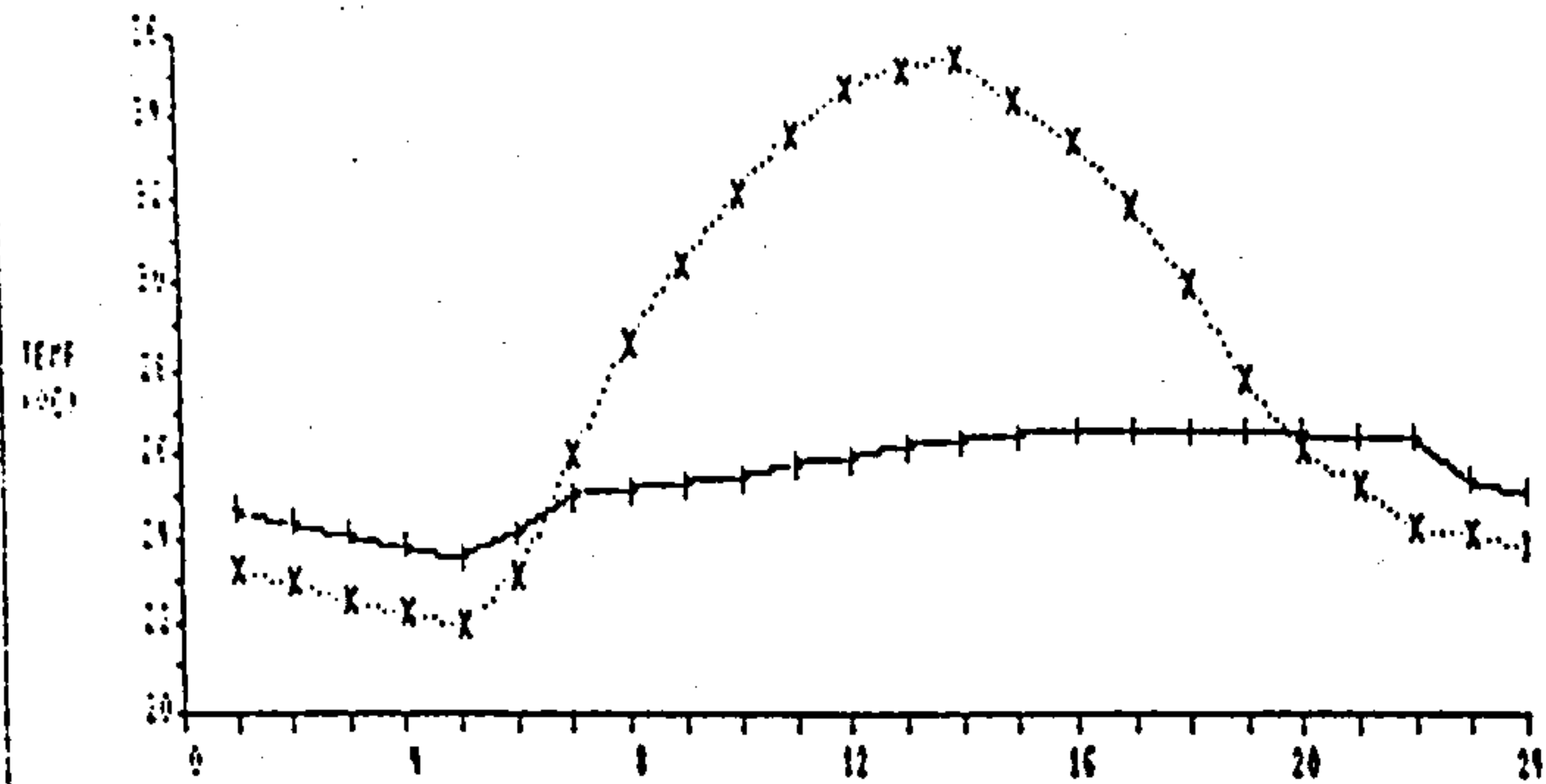


# TEMPERATURE SIMULATION FOR HOT DAY



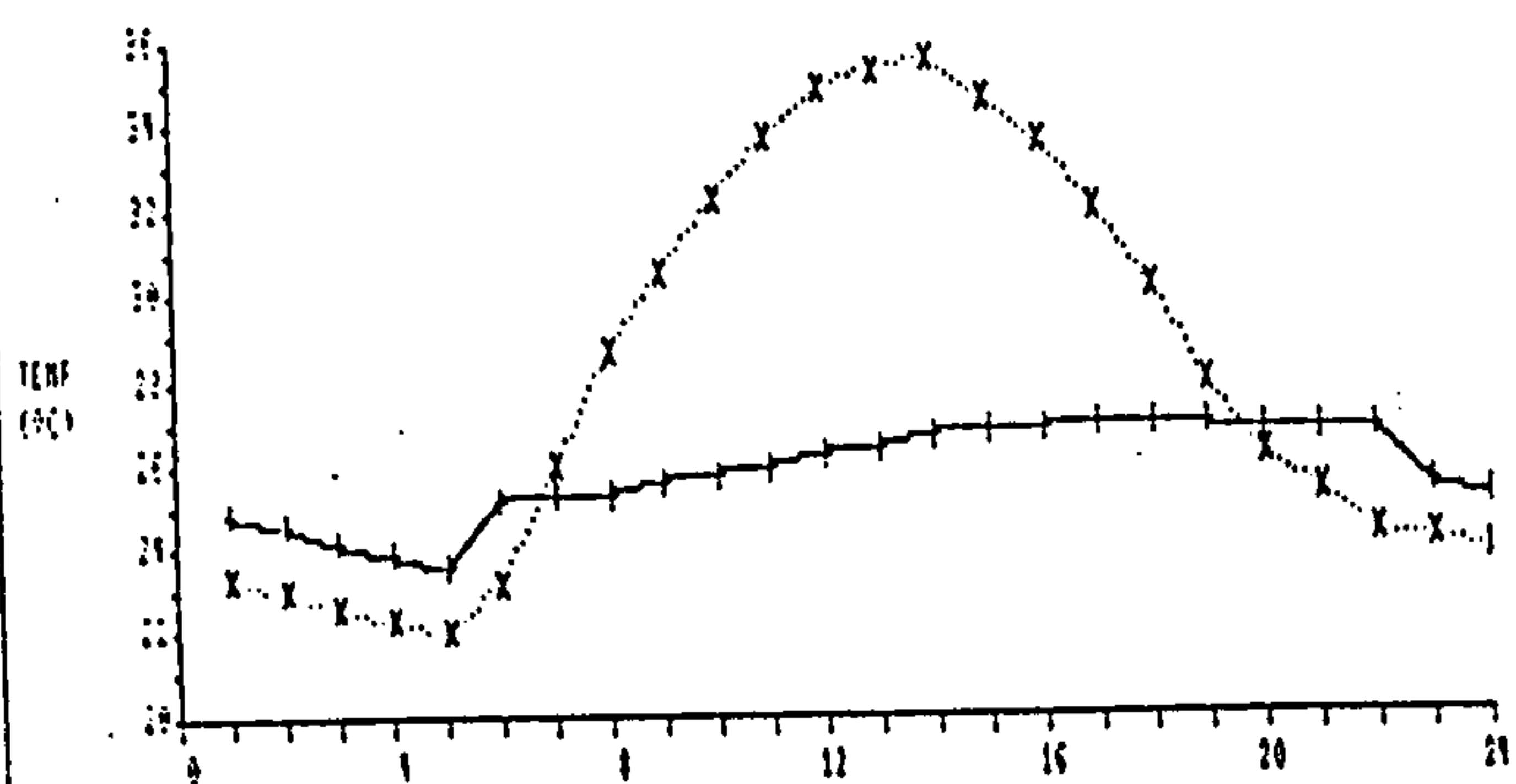
PROJECT: ZERO HQ  
 ZONE: VENT BAS  
 GRAPH 5.2.1.0: OPTIMIZED-ALL WINDOWS OPEN (22.00-06.00HRS)

# TEMPERATURE SIMULATION FOR HOT DAY



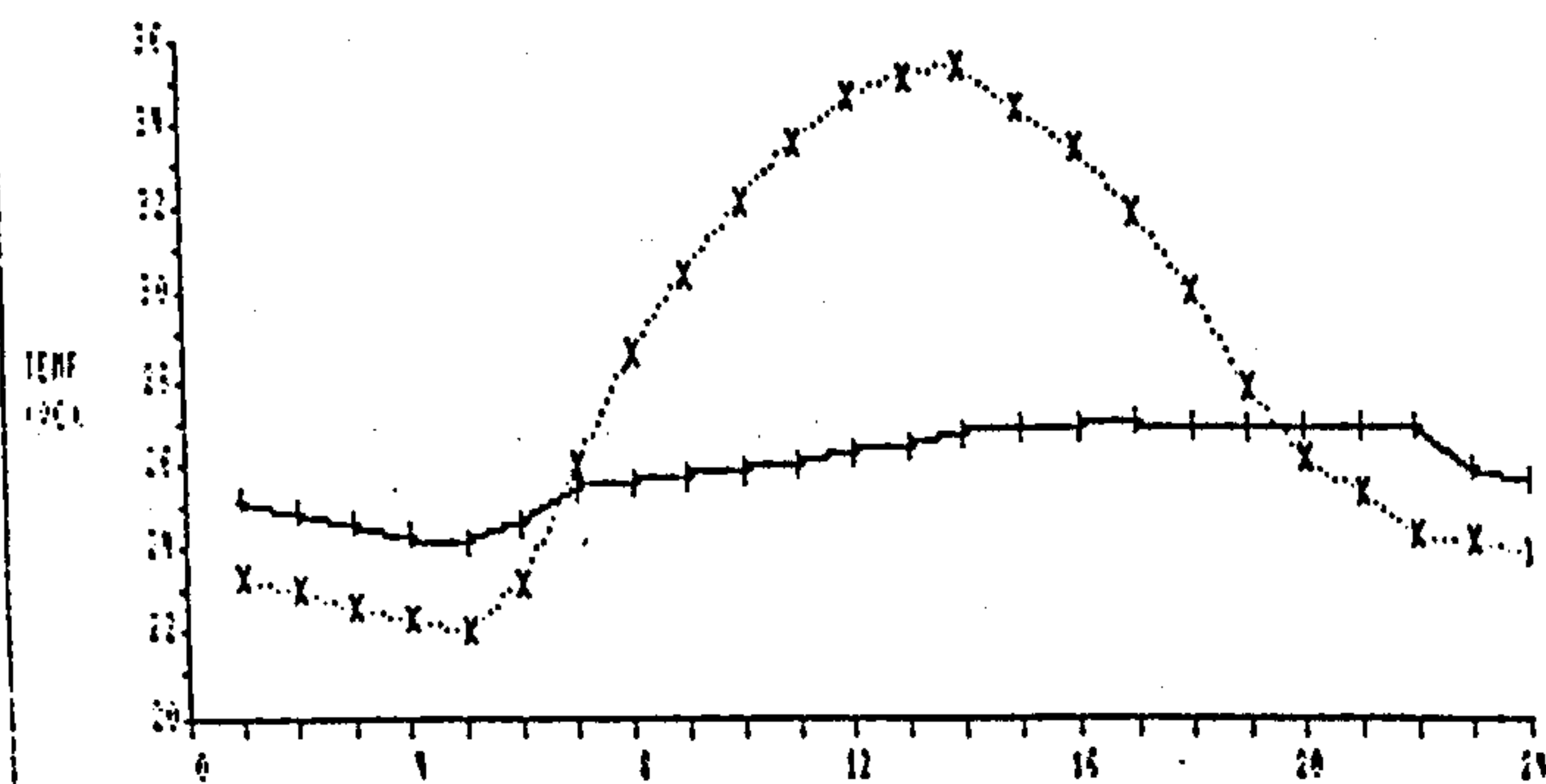
PROJECT: ZERO HQ  
 ZONE: VENT ST  
 GRAPH 5.2.1.1: 1M2 CLOSED WINDOW AREA (22.00-06.00)

# TEMPERATURE SIMULATION FOR HOT DAY



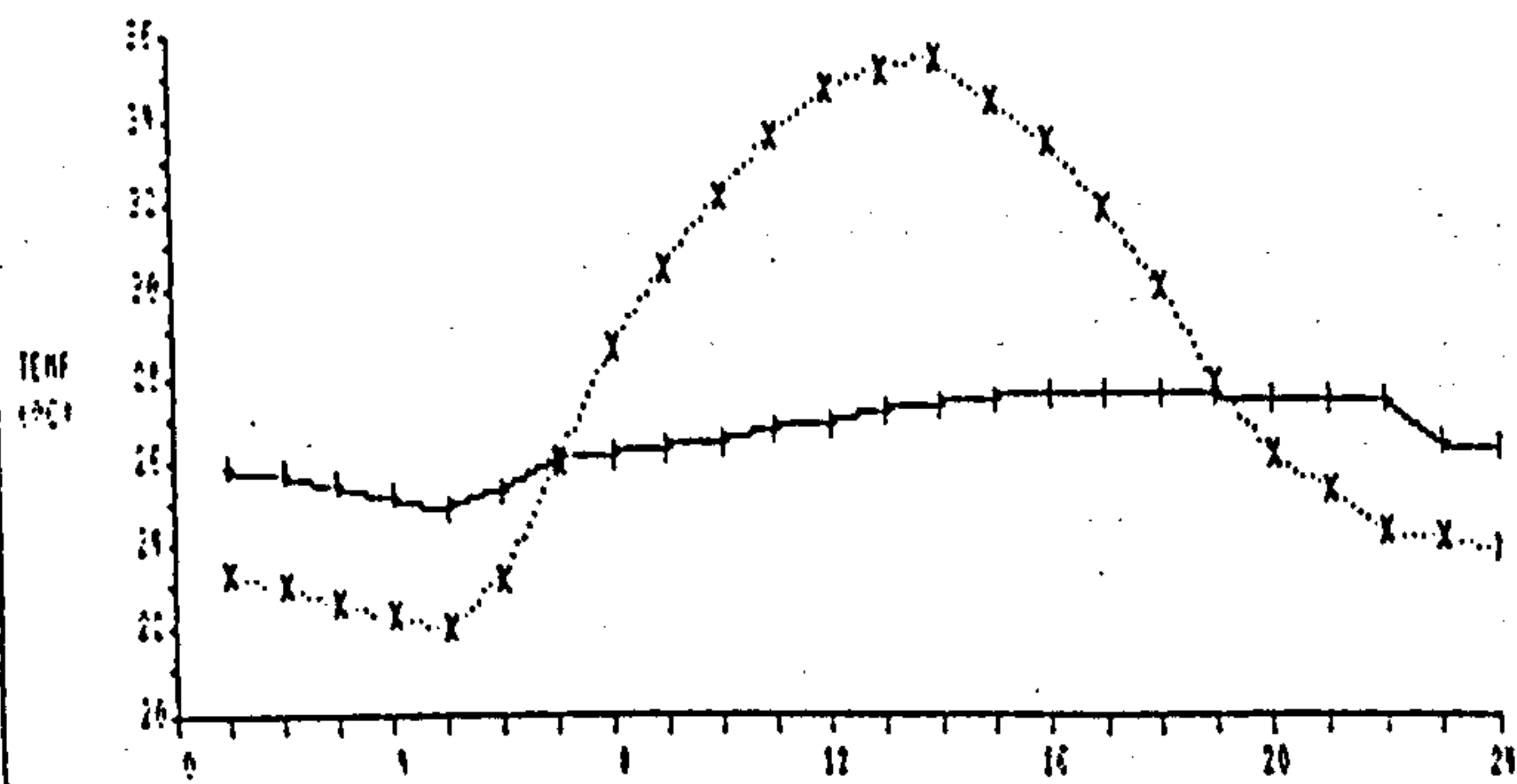
PROJECT: ZERO HQ  
 ZONE: VENT ST  
 GRAPH 5.2.1.2: 3.5M2 CLOSED WINDOW AREA (22.00-06.00)

# TEMPERATURE SIMULATION FOR HOT DAY



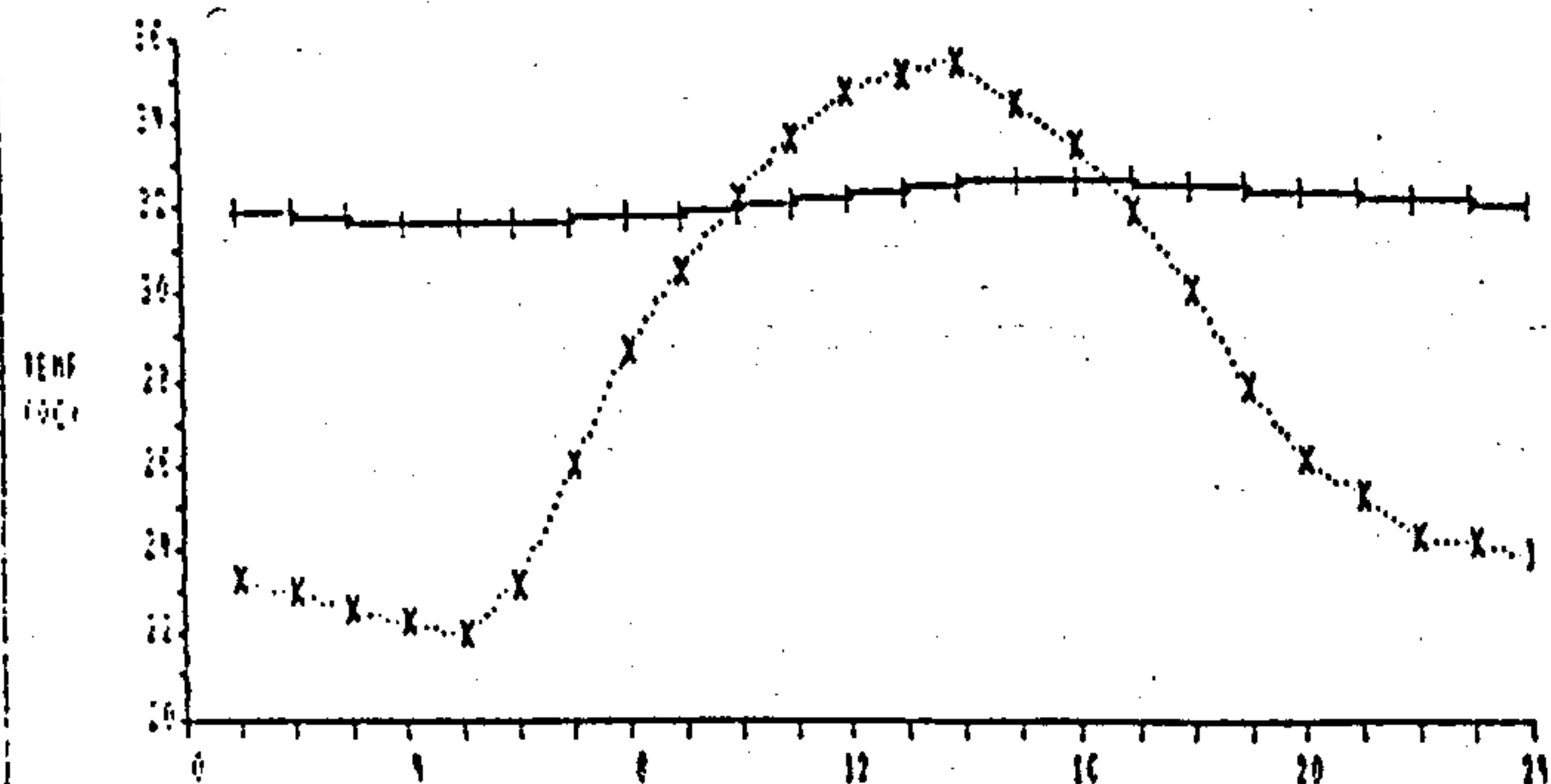
PROJECT: ZERO HQ  
 ZONE: VENT ST  
 GRAPH 5.2.1.3: 12.5M2 CLOSED WINDOW AREA (22.00-06.00)

# TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
 ZONE: VENT ST  
 GRAPH 5.2.1.4: 17.5M2 CLOSED WINDOW AREA (22.00-06.00)

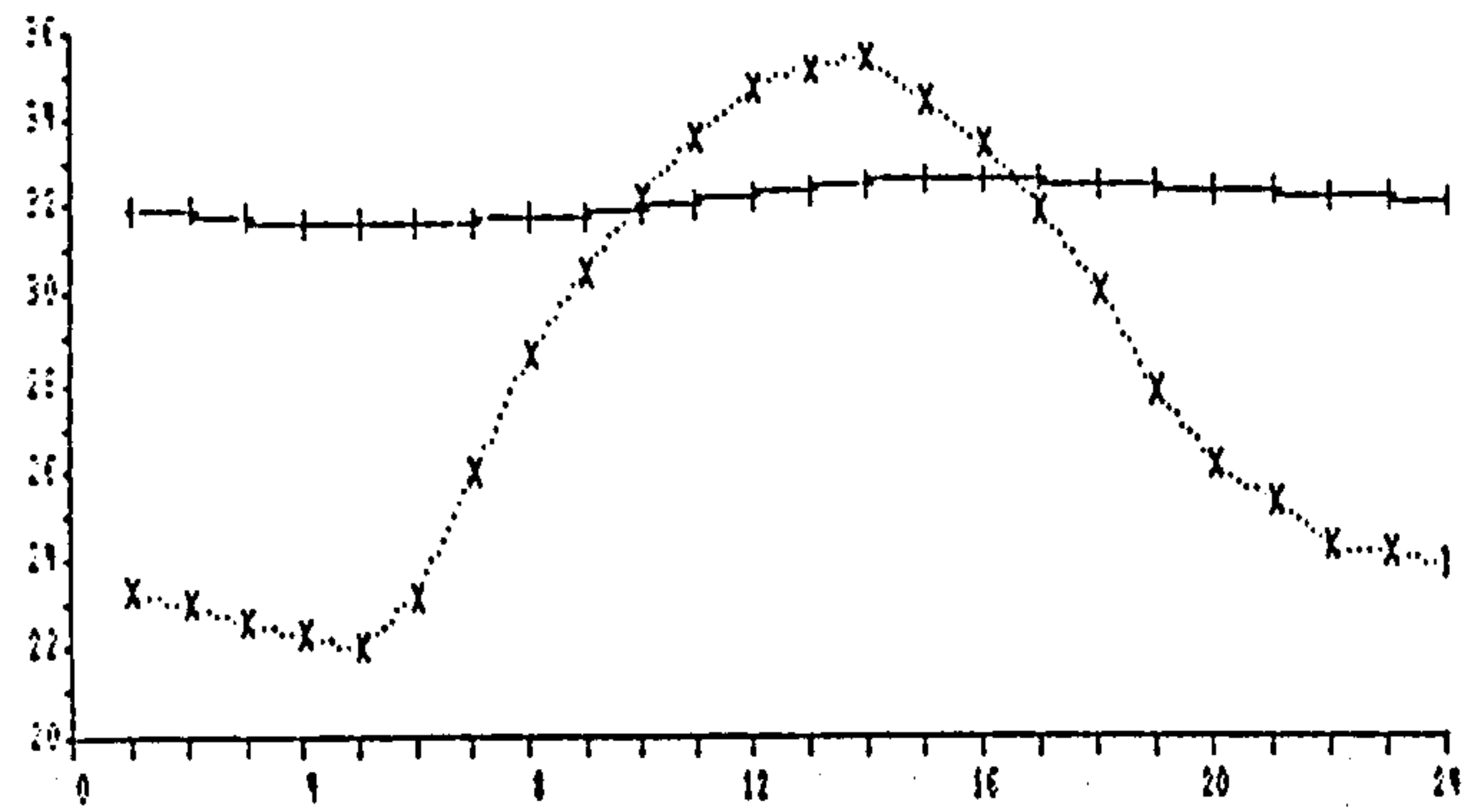
# TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HQ  
 ZONE: VENT ST  
 GRAPH 5.2.1.5: 22M2 CLOSED WINDOW AREA (22.00-06.00)

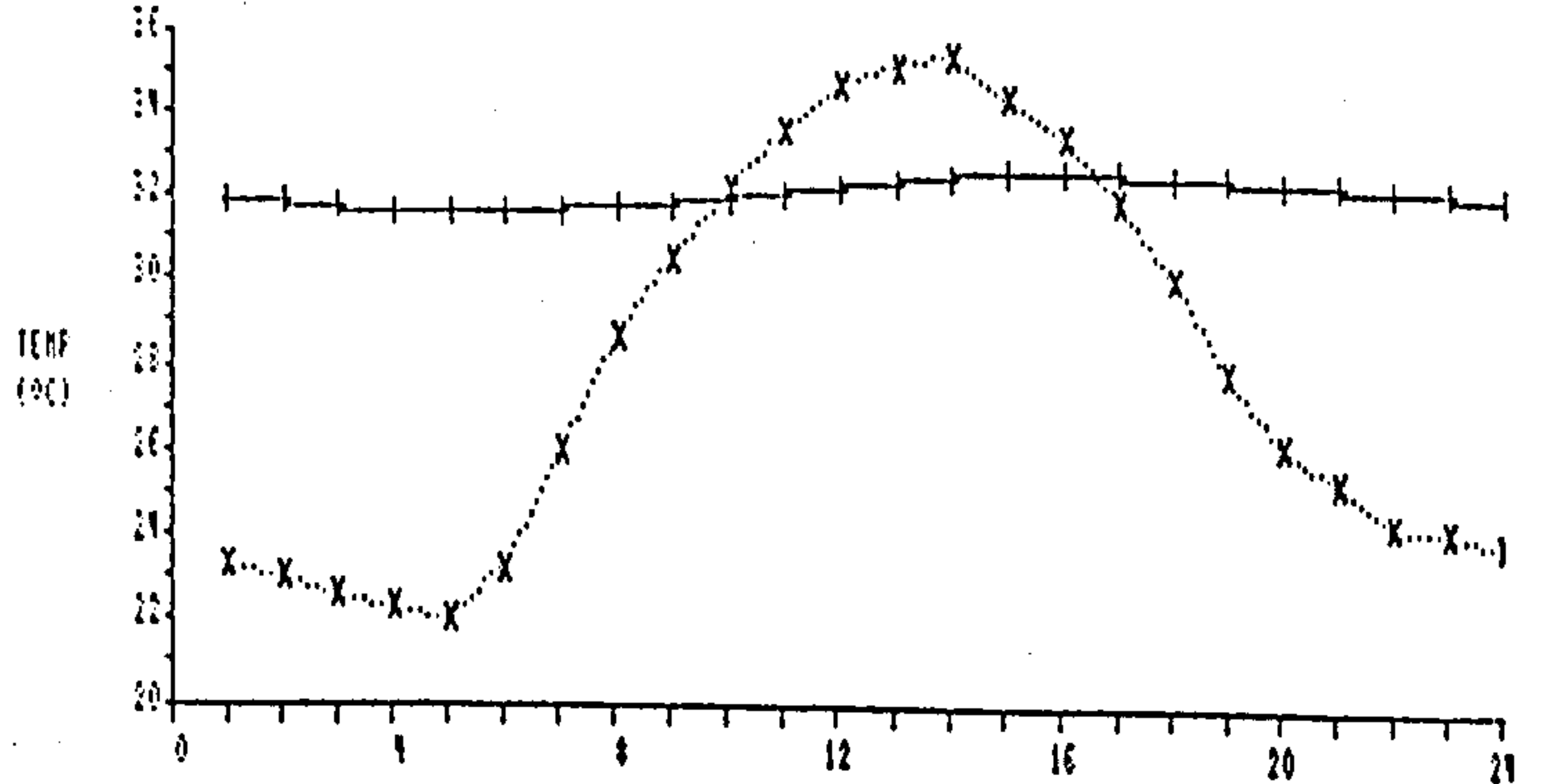


# TEMPERATURE SIMULATION FOR HOT DAY



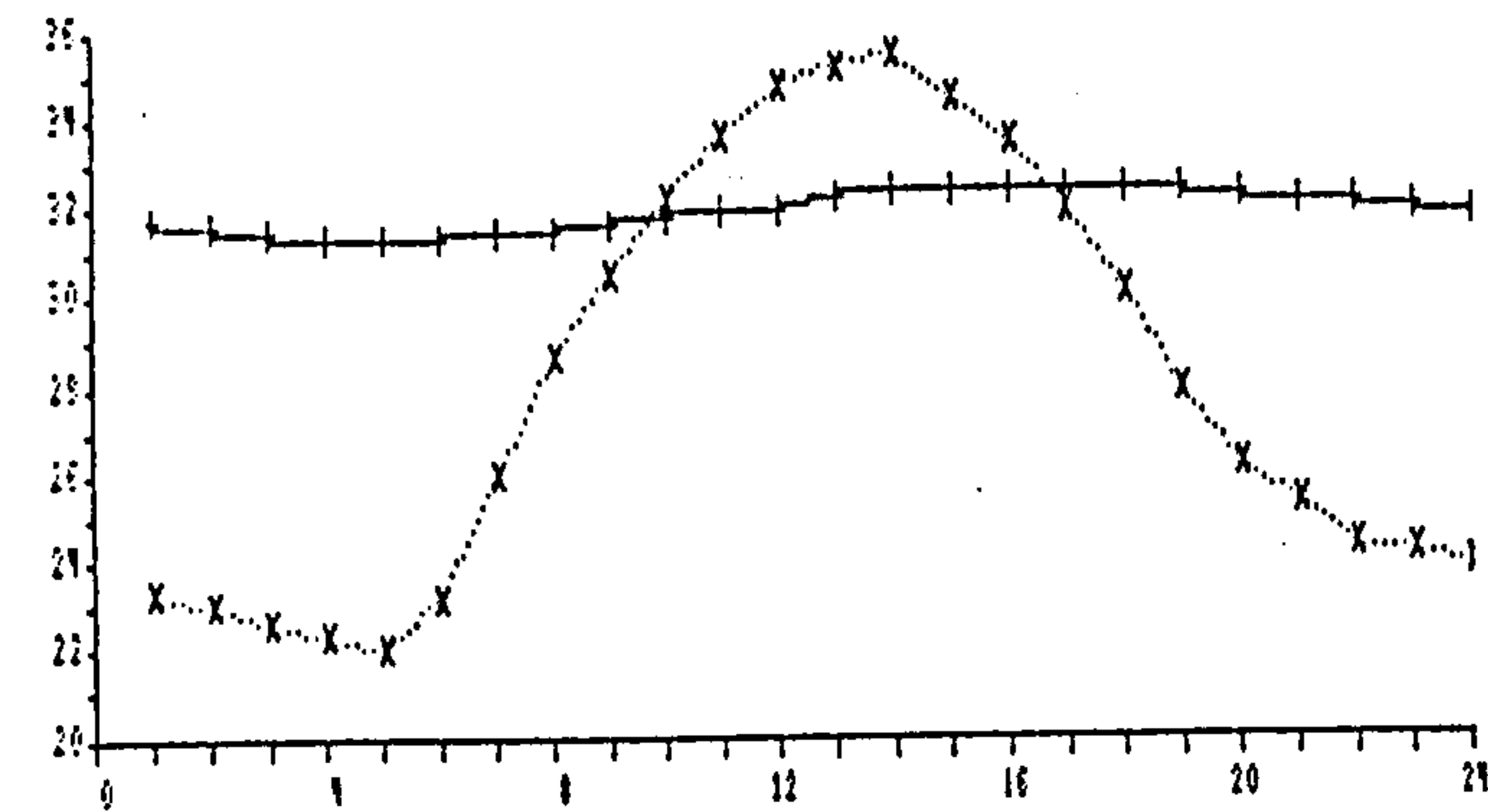
PROJECT: ZERO HD  
 ZONE: VENT 56  
 GRAPH 5.2.1.5: 30M2 CLOSED WINDOW AREA (22.00-06.00)

# TEMPERATURE SIMULATION FOR HOT DAY



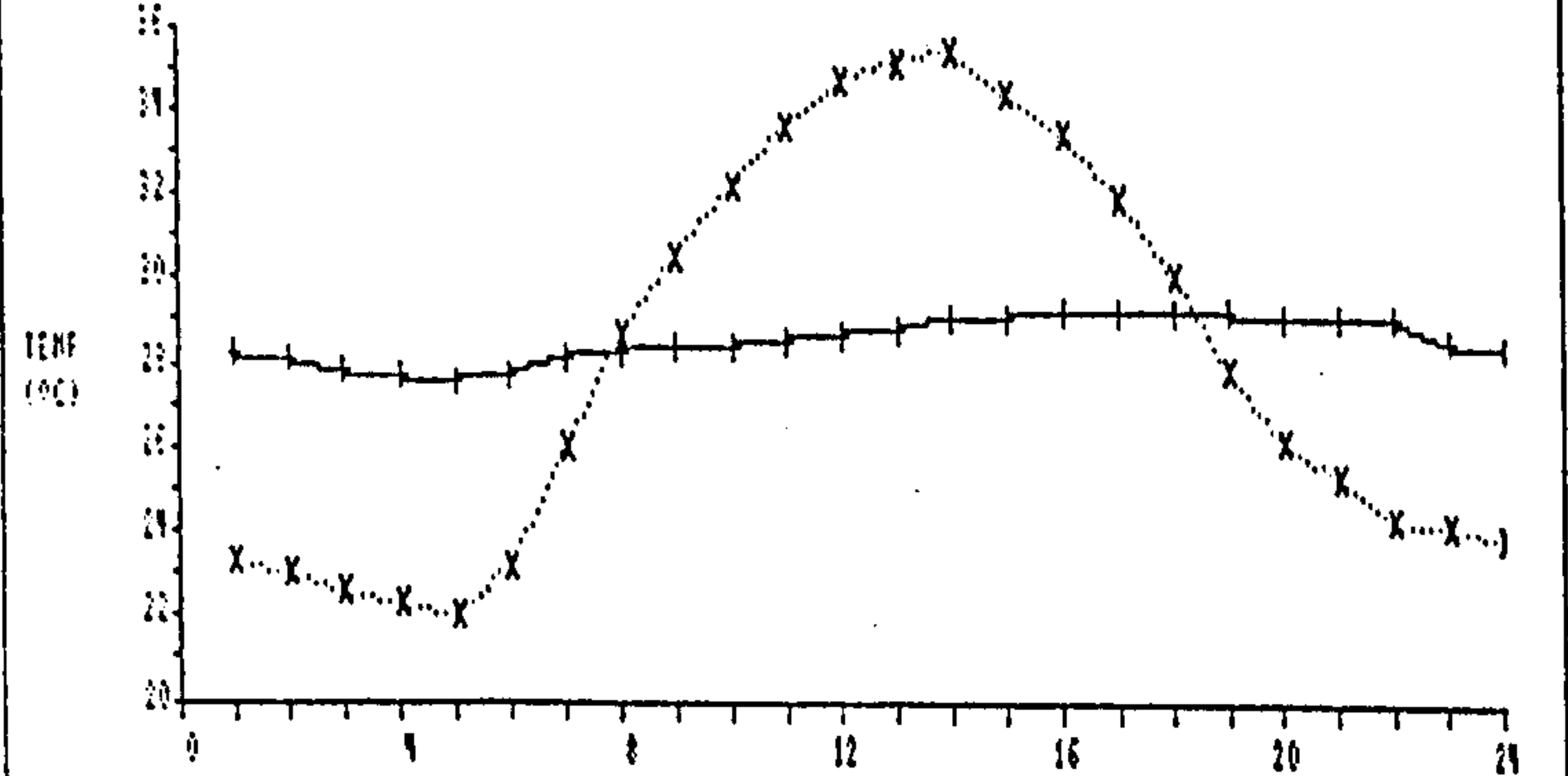
PROJECT: ZERO HD  
 ZONE: VENT 57  
 GRAPH 5.2.1.7: 35M2 CLOSED WINDOW AREA (22.00-06.00)

# TEMPERATURE SIMULATION FOR HOT DAY



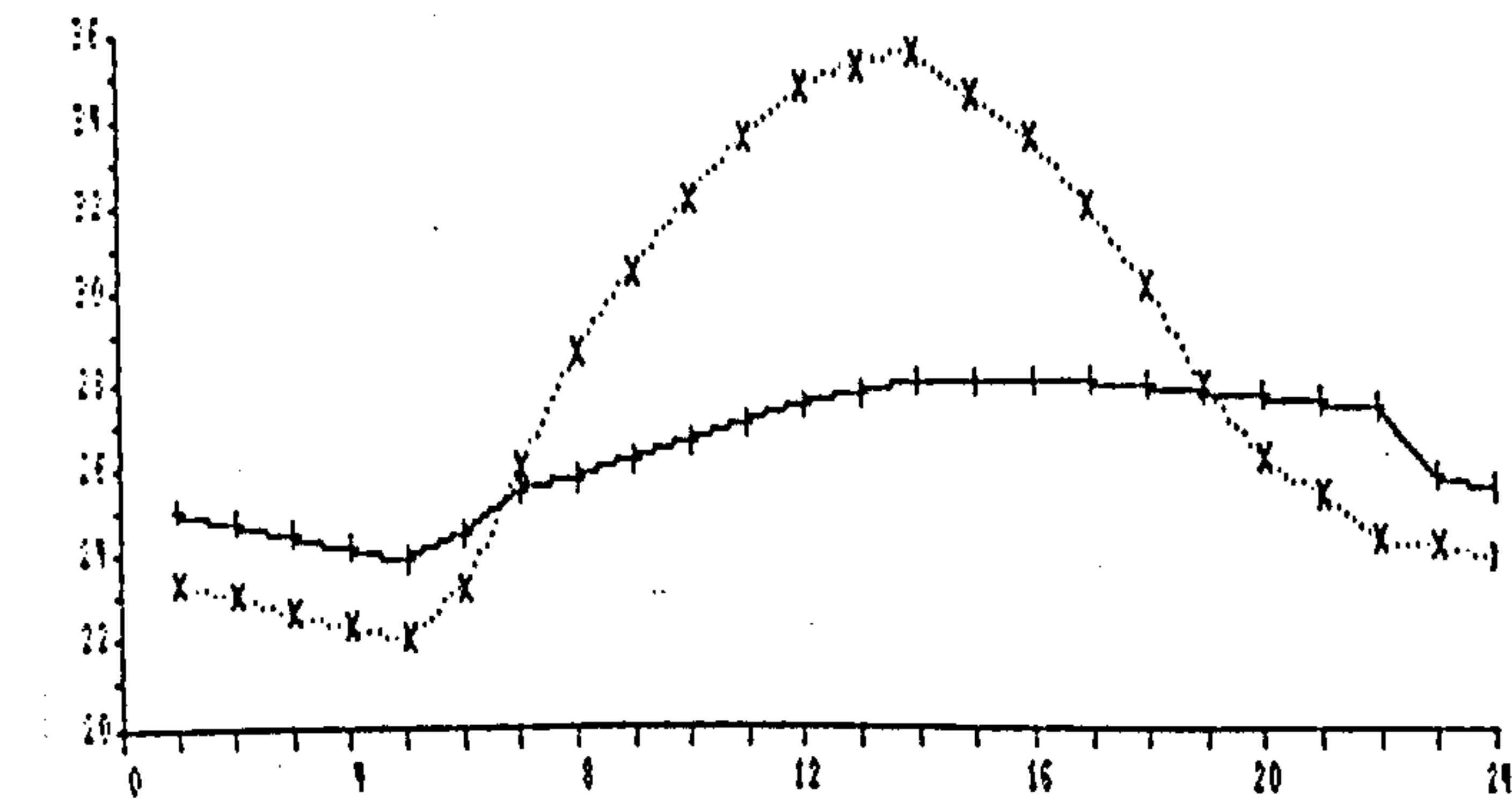
PROJECT: ZERO HD  
 ZONE: VENT 58  
 GRAPH 5.2.1.8: 40M2 CLOSED WINDOW AREA (22.00-06.00 HRS)

# TEMPERATURE SIMULATION FOR HOT DAY



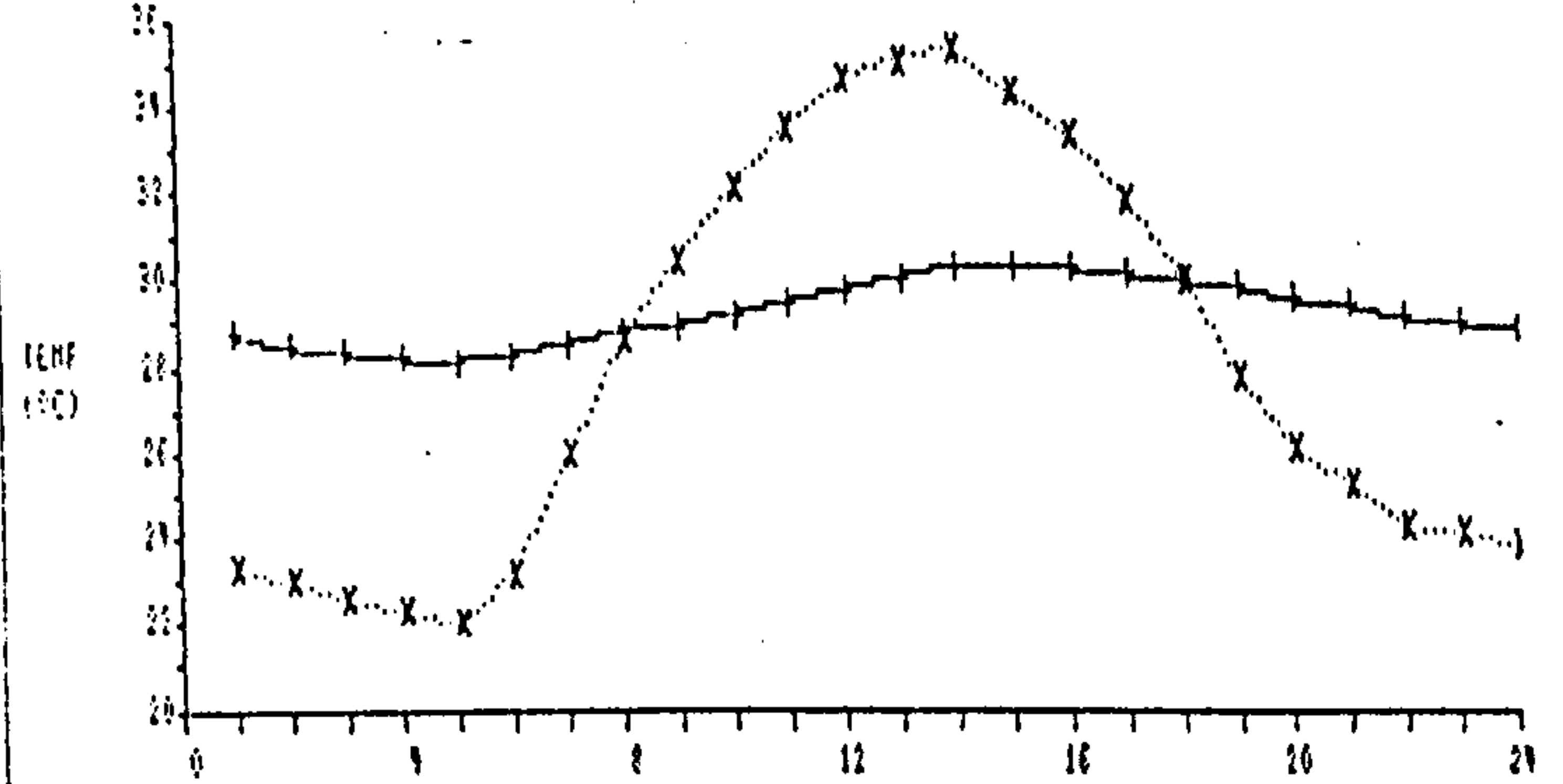
PROJECT: ZERO HD  
 ZONE: UE\_S01-1 A=1M H.065M 0-24  
 GRAPH 5.2.1.9: 2M2 OPEN WINDOW AREA 1M55M H (06.00-22.00)

# TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HD  
 ZONE: UE\_S01-1 A=1M H.065M 0-24  
 GRAPH 5.2.1.9: 2M2 OPEN WINDOW AREA AT 1M55M HGT (24 HRS)

# TEMPERATURE SIMULATION FOR HOT DAY



PROJECT: ZERO HD  
 ZONE: UE\_S01-1 A=1M H.065M 0-24  
 GRAPH 5.2.1.10: 2M2 OPEN WINDOW AREA AT 1M55M HGT (24 HRS)



Table 5.2.2.0 Optimized Strategy

Summer: Days - All Windows closed

Nights- All Windows open - 40.0m2

Winter: All windows closed (00.00-24.00 Hours)

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.6	18.7	13	35.1	13.8	26.1	19.8
2	23.0	7.0	24.3	18.5	14	35.4	14.1	26.3	19.9
3	22.6	6.8	24.0	18.4	15	34.4	13.5	26.5	19.9
4	22.3	6.7	23.7	18.3	16	33.4	12.7	26.6	19.8
5	22.0	6.5	23.4	18.1	17	31.9	11.5	26.6	19.7
6	23.1	6.5	24.9	18.1	18	30.0	10.5	26.6	19.5
7	25.9	6.6	25.0	18.2	19	27.8	9.7	26.6	19.4
8	28.6	7.4	25.2	18.4	20	26.1	9.0	26.6	19.3
9	30.5	10.0	25.3	18.7	21	25.2	8.5	26.5	19.2
10	32.2	11.8	25.5	19.0	22	24.3	8.0	26.5	19.0
11	33.6	12.9	25.7	19.3	23	24.1	7.6	25.3	18.9
12	34.7	13.6	25.9	19.6	24	23.8	7.3	25.0	18.8

Table 5.2.2.25: 43.0M2 Open Window Area

South : 17.5m2 - 0.2m Height

South : 17.5m2 - 5.0m Height

North : 3.5m2 - 1.0m Height

North : 4.0m2 - 5.0m Height

West : 0.5m2 - 6.0m Height

Summer: 06.00-22.00 Hours

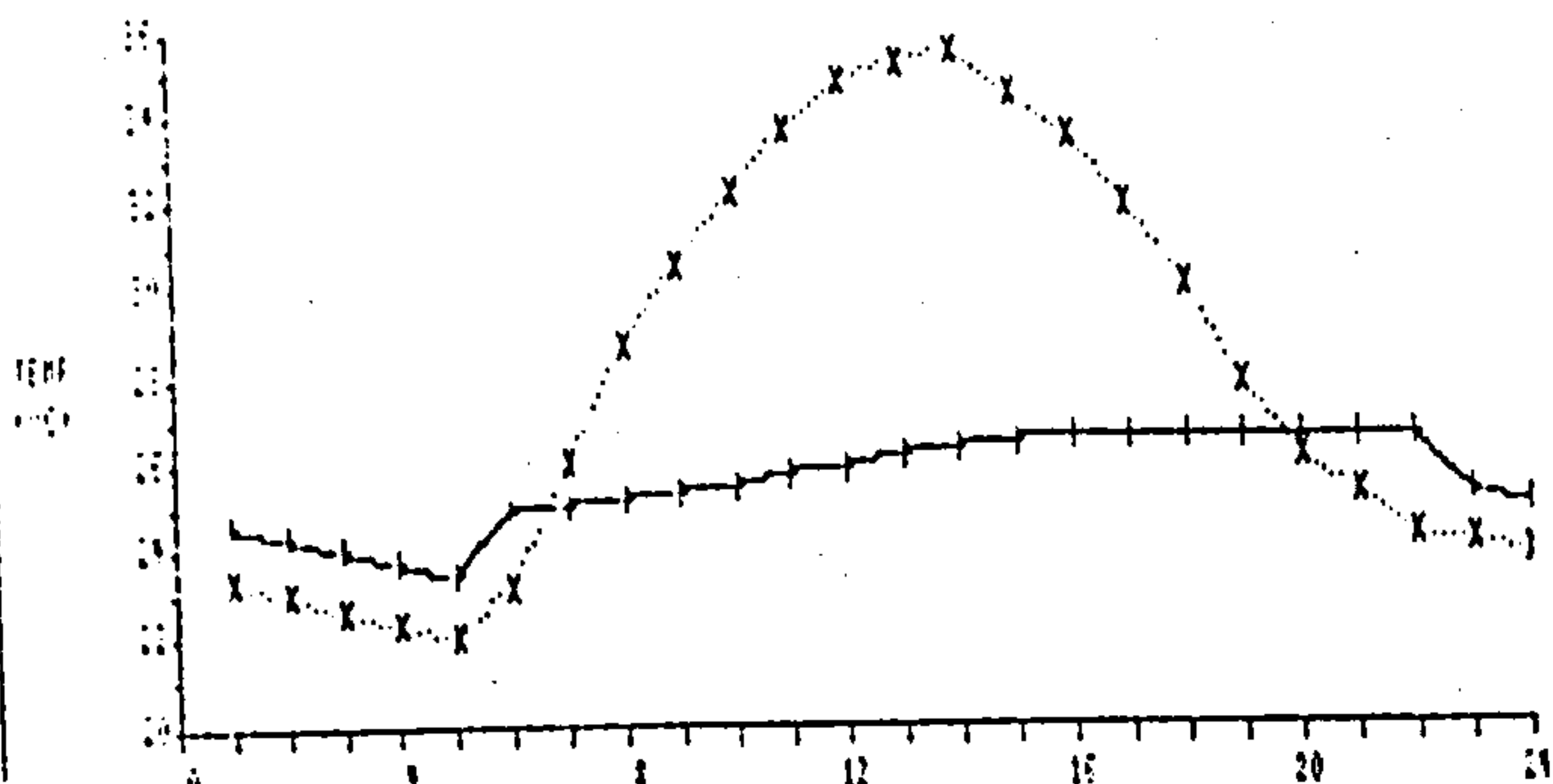
Winter: 00.00-24.00 Hours

RESULTS OF TEMPERATURE SIMULATION FOR HOT AND COLD DAYS [°C]

Hour	Outdoor Temp		Indoor Temp		Hour	Outdoor Temp		Indoor Temp	
	Hot	Cold	Hot	Cold		Hot	Cold	Hot	Cold
1	23.3	7.1	24.7	12.0	13	35.1	13.8	26.9	13.1
2	23.0	7.0	24.4	11.8	14	35.4	14.1	27.2	13.4
3	22.6	6.8	24.1	11.7	15	34.4	13.5	27.3	12.9
4	22.3	6.7	23.8	11.6	16	33.4	12.7	27.5	12.9
5	22.0	6.5	23.5	11.4	17	31.9	11.5	27.5	12.8
6	23.1	6.5	25.4	8.5	18	30.0	10.5	27.5	12.7
7	25.9	6.6	25.5	8.5	19	27.8	9.7	27.5	12.6
8	28.6	7.4	25.7	9.0	20	26.1	9.0	27.4	12.5
9	30.5	10.0	25.9	10.6	21	25.2	8.5	27.3	12.4
10	32.2	11.8	26.1	11.6	22	24.3	8.0	25.6	12.3
11	33.6	12.9	26.4	12.3	23	24.1	7.6	25.4	12.1
12	34.7	13.6	26.6	12.9	24	23.8	7.3	25.1	12.0



# TEMPERATURE SIMULATION FOR HOT DAY

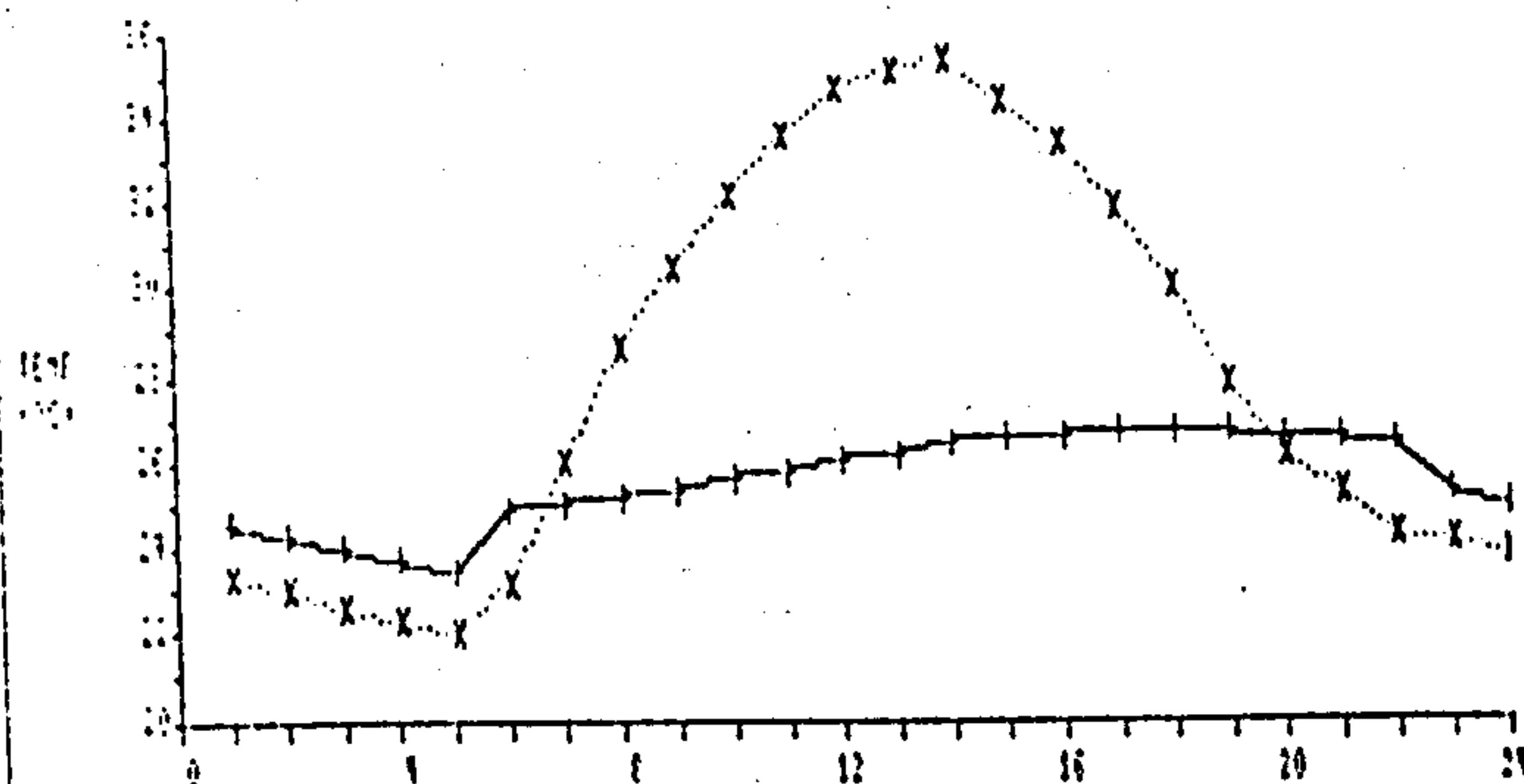


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: OPTIMIZED-ALL CLOSED DAY - ALL OPEN NIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE

# TEMPERATURE SIMULATION FOR HOT DAY

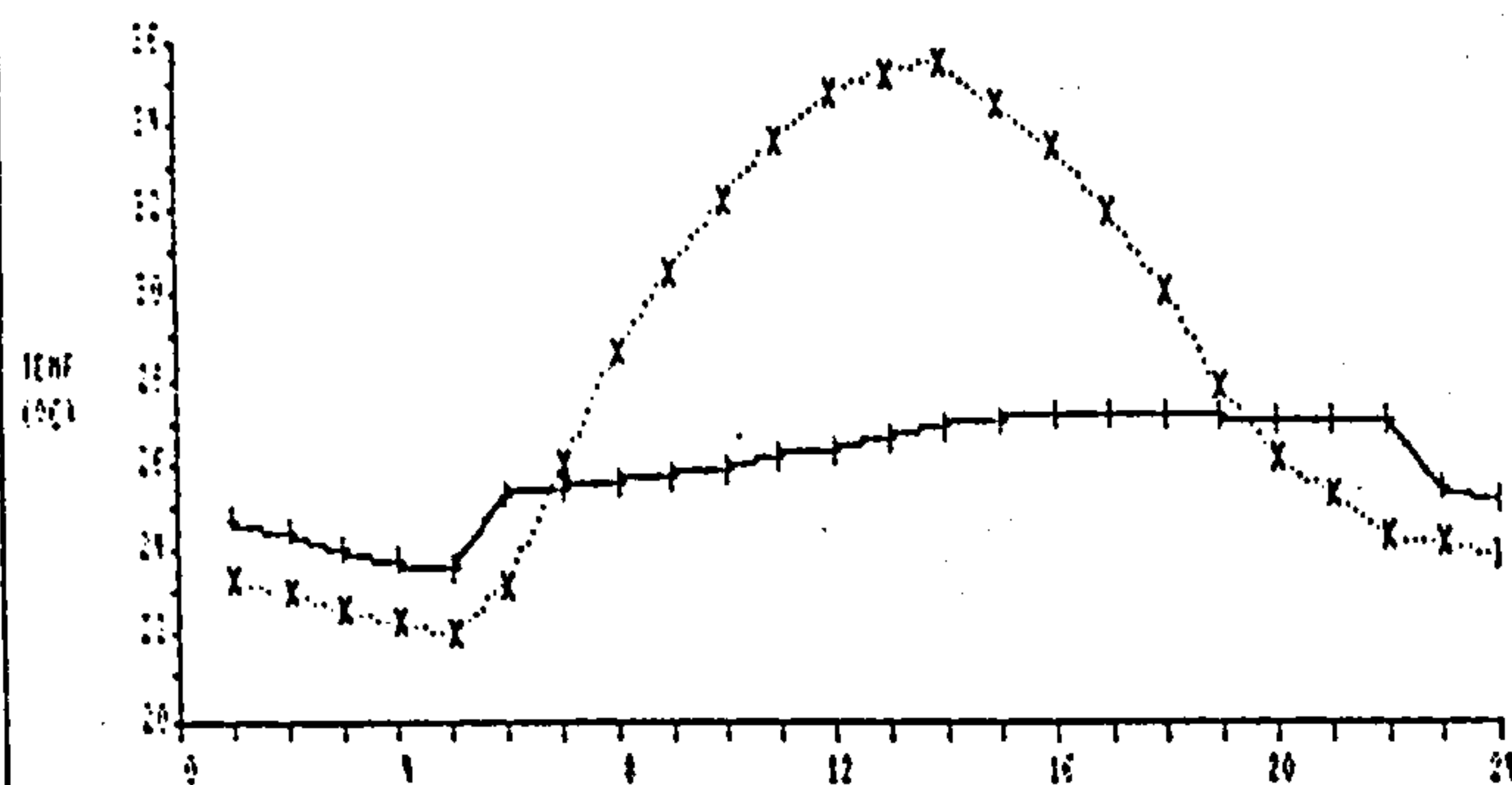


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: 06.00-22.00-ALL 22.00-06.

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE

# TEMPERATURE SIMULATION FOR HOT DAY

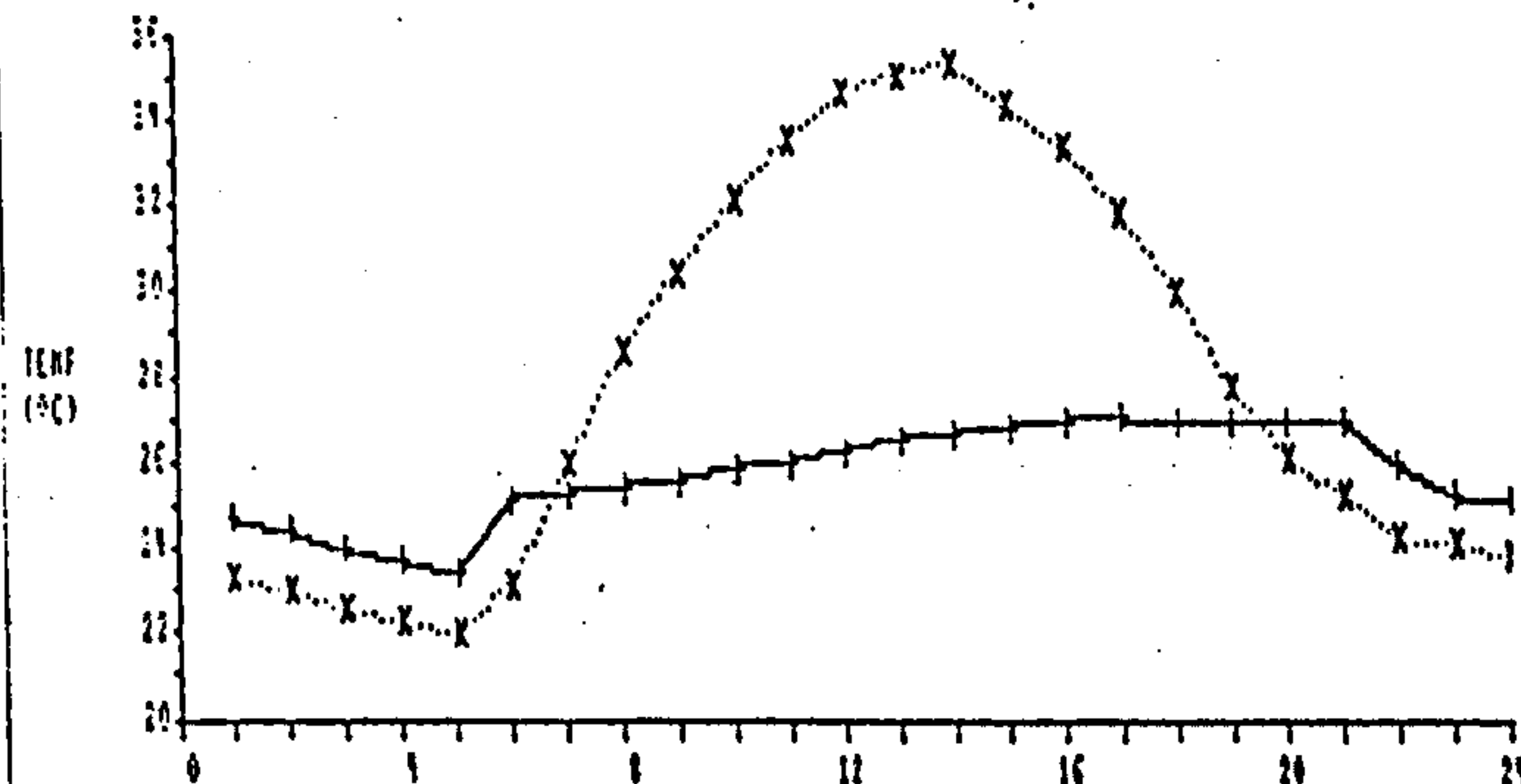


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: 06.00-22.00-ALL 22.00-06.

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE

# TEMPERATURE SIMULATION FOR HOT DAY

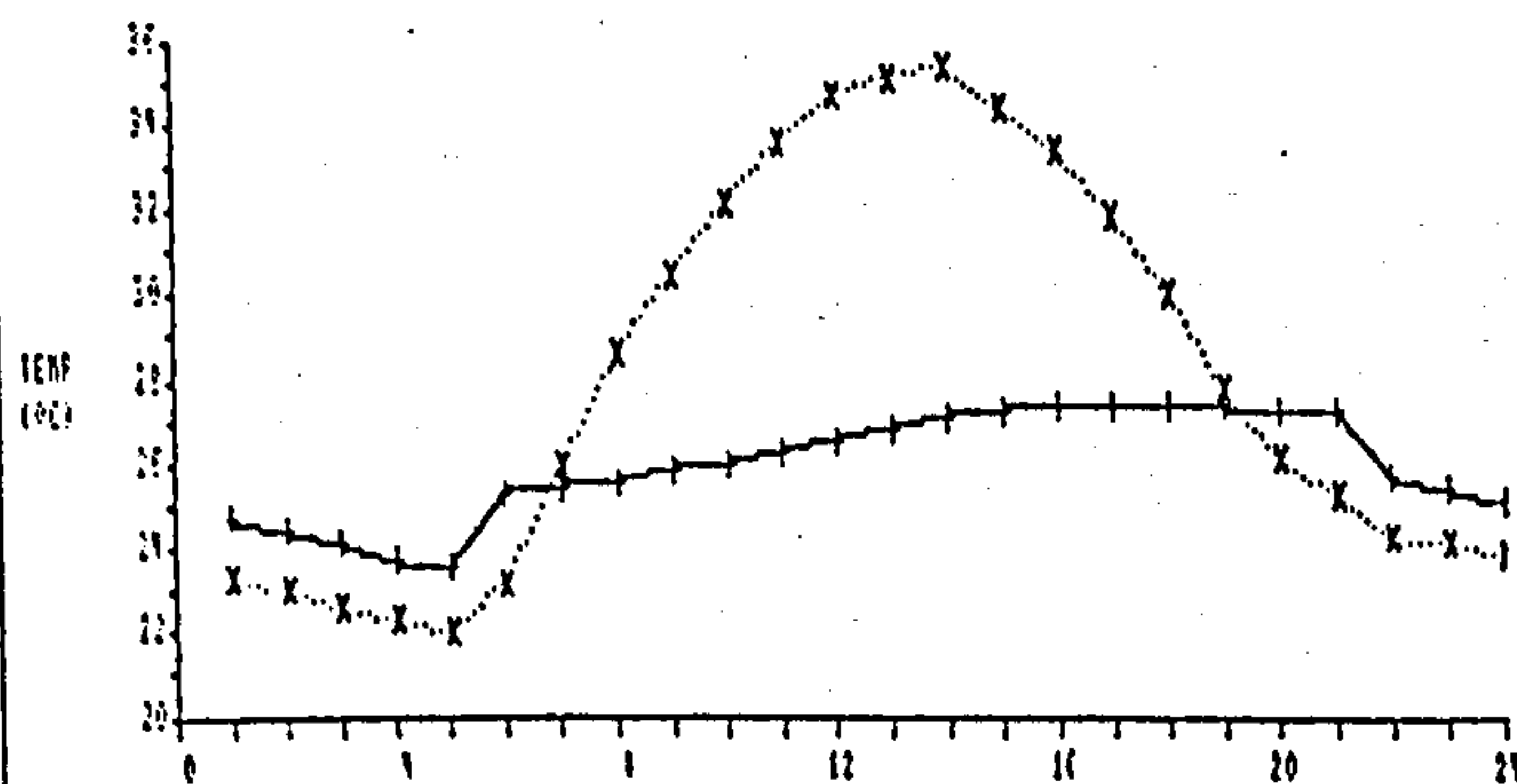


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: 06.00-22.00-ALL 22.00-06.

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE

# TEMPERATURE SIMULATION FOR HOT DAY

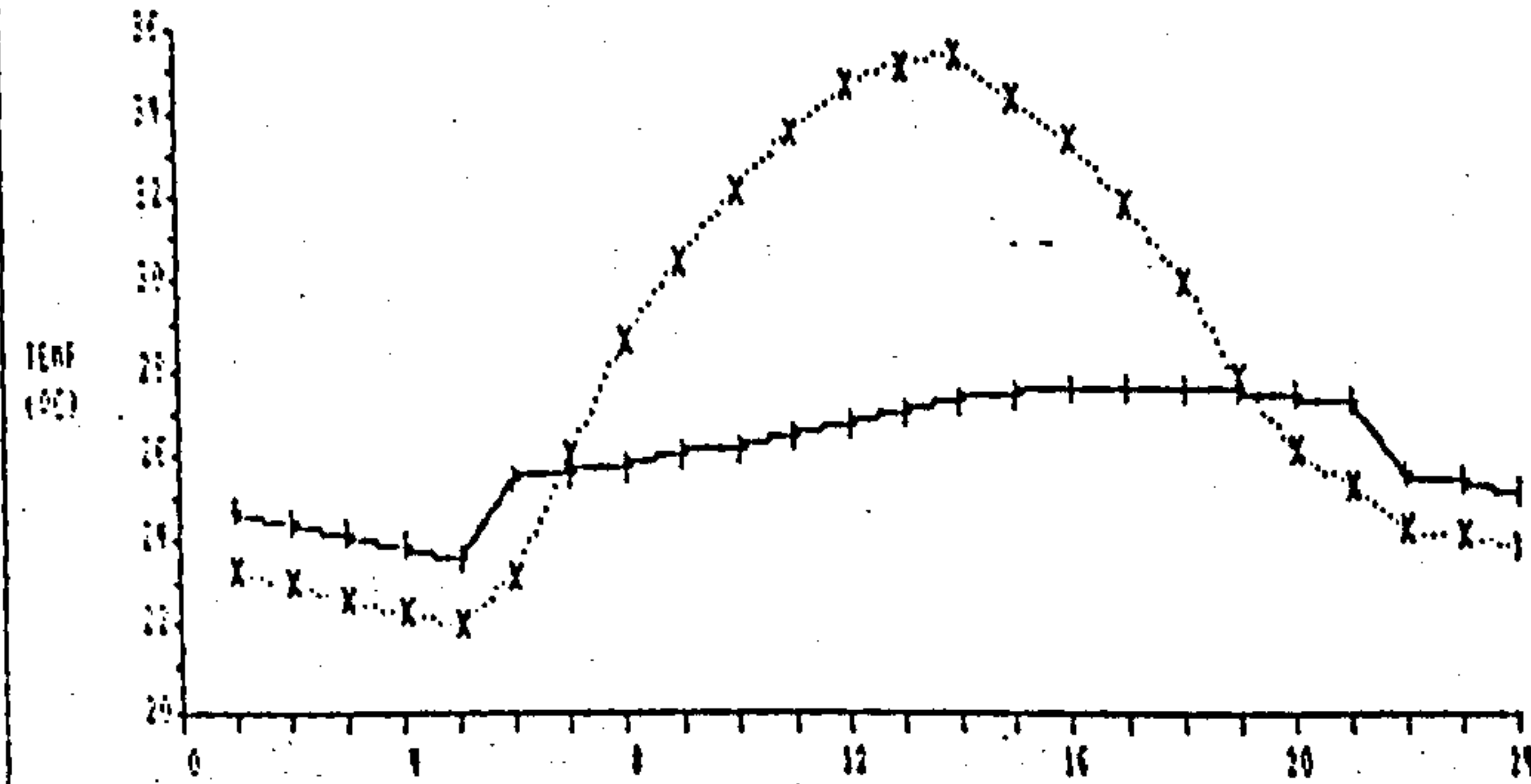


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: 06.00-22.00-ALL 22.00-06.

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE

# TEMPERATURE SIMULATION FOR HOT DAY

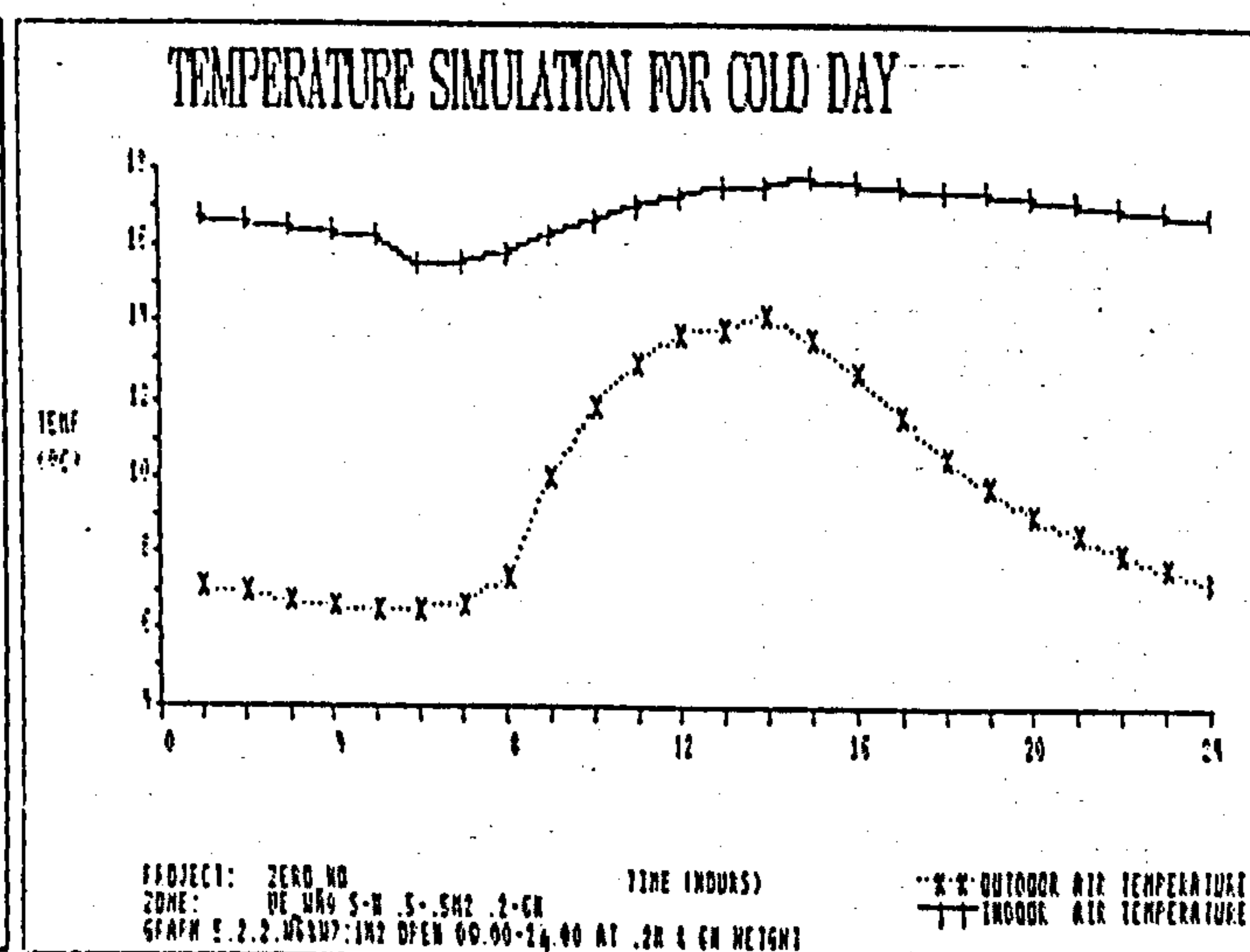
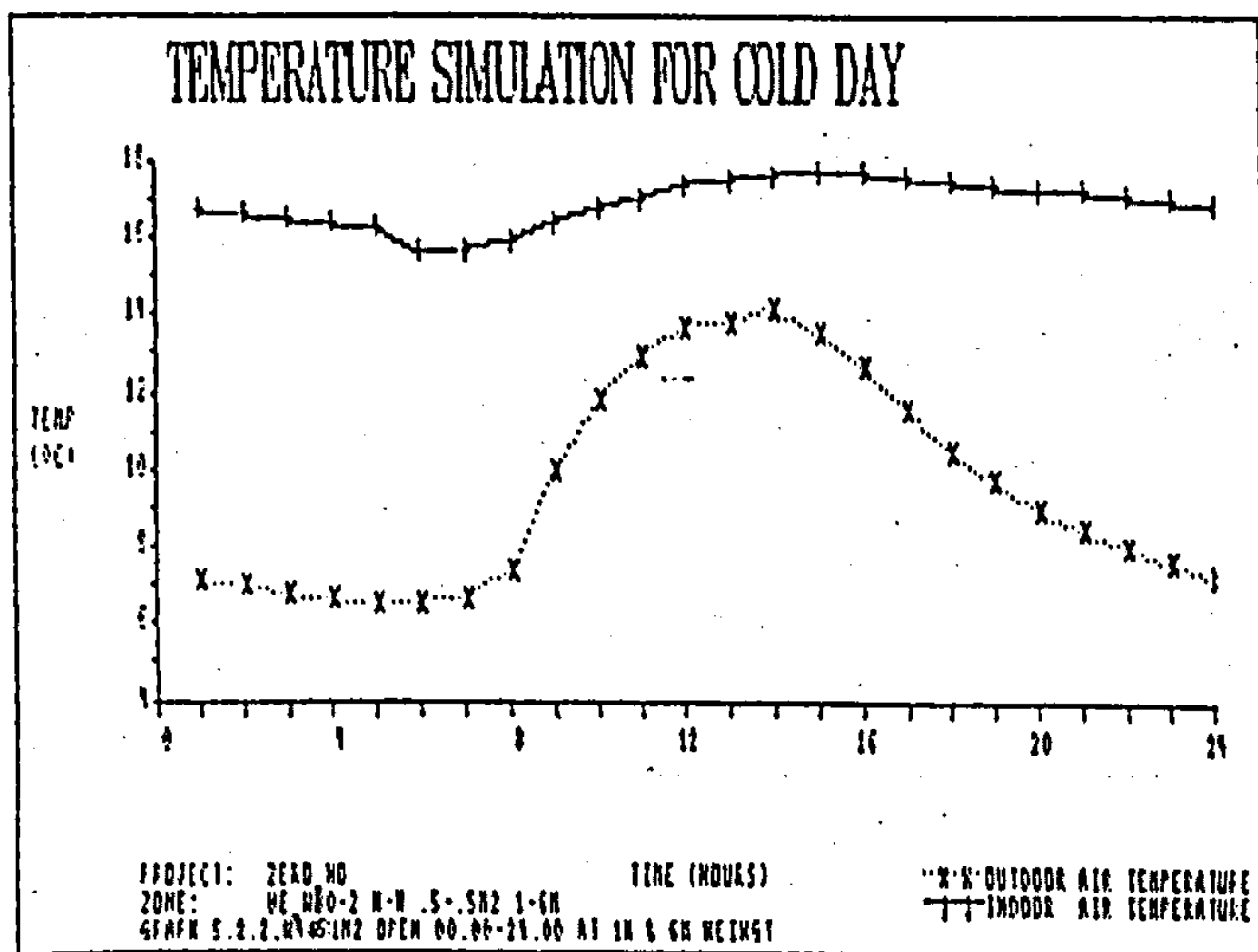
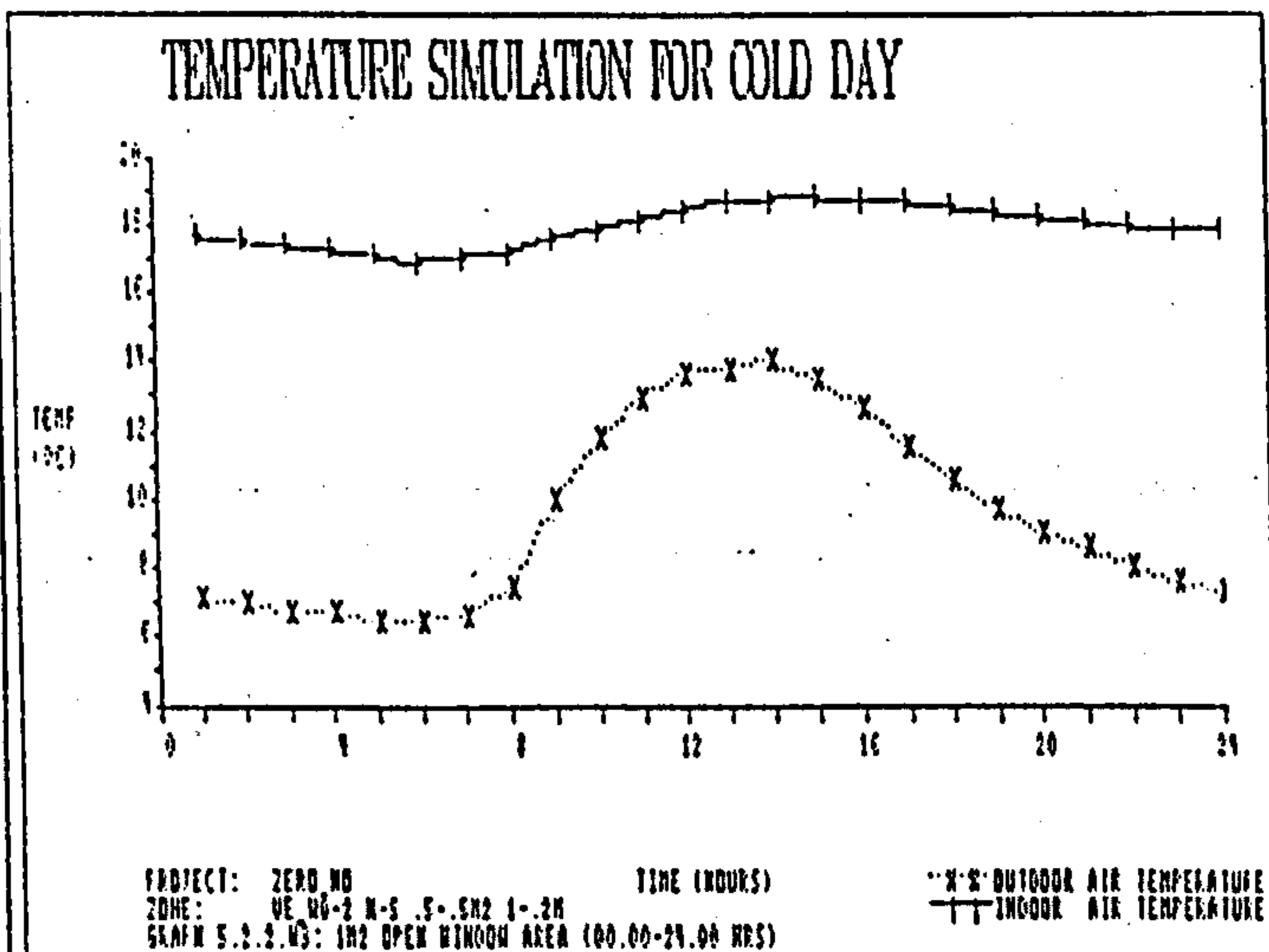
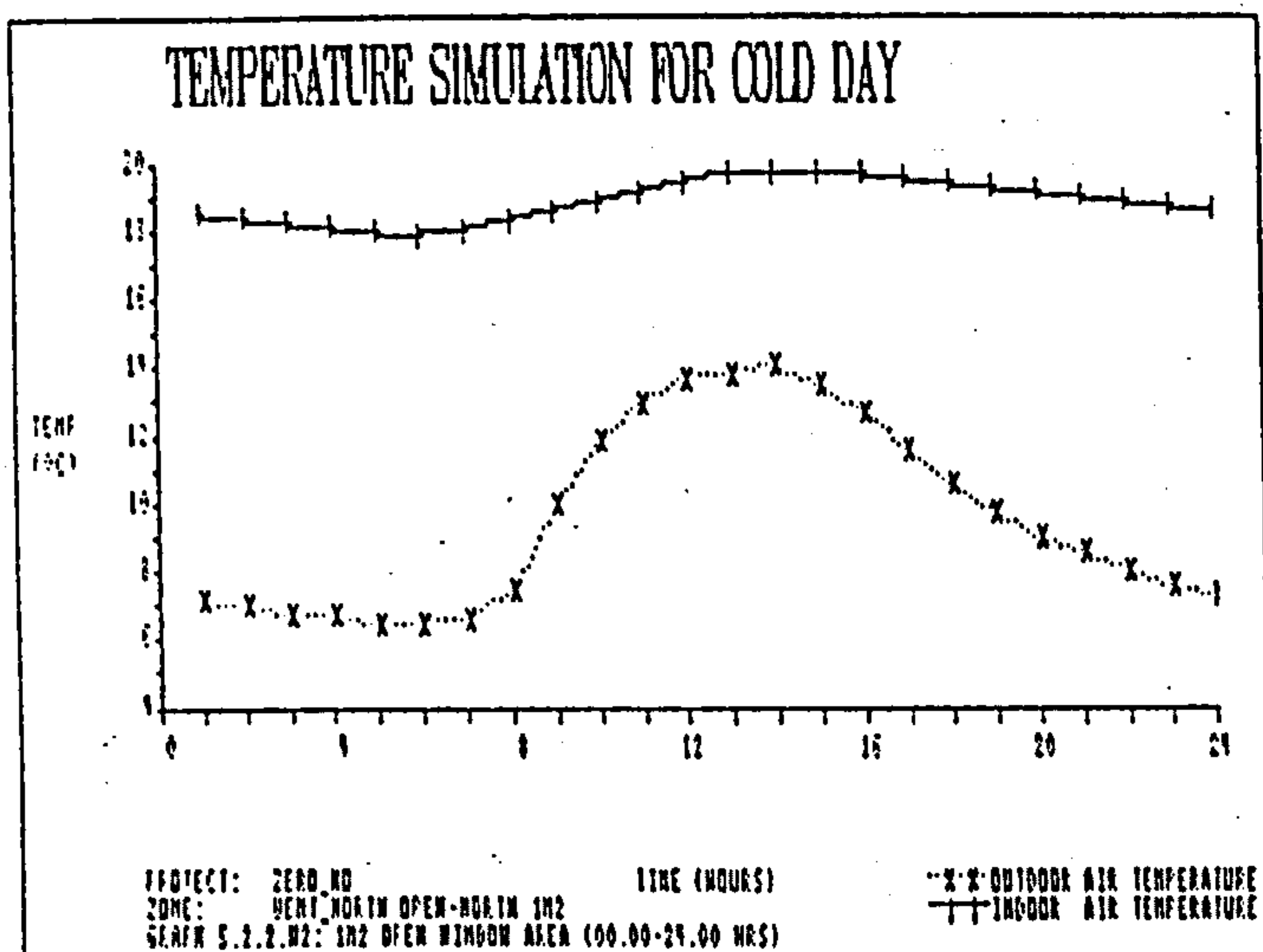
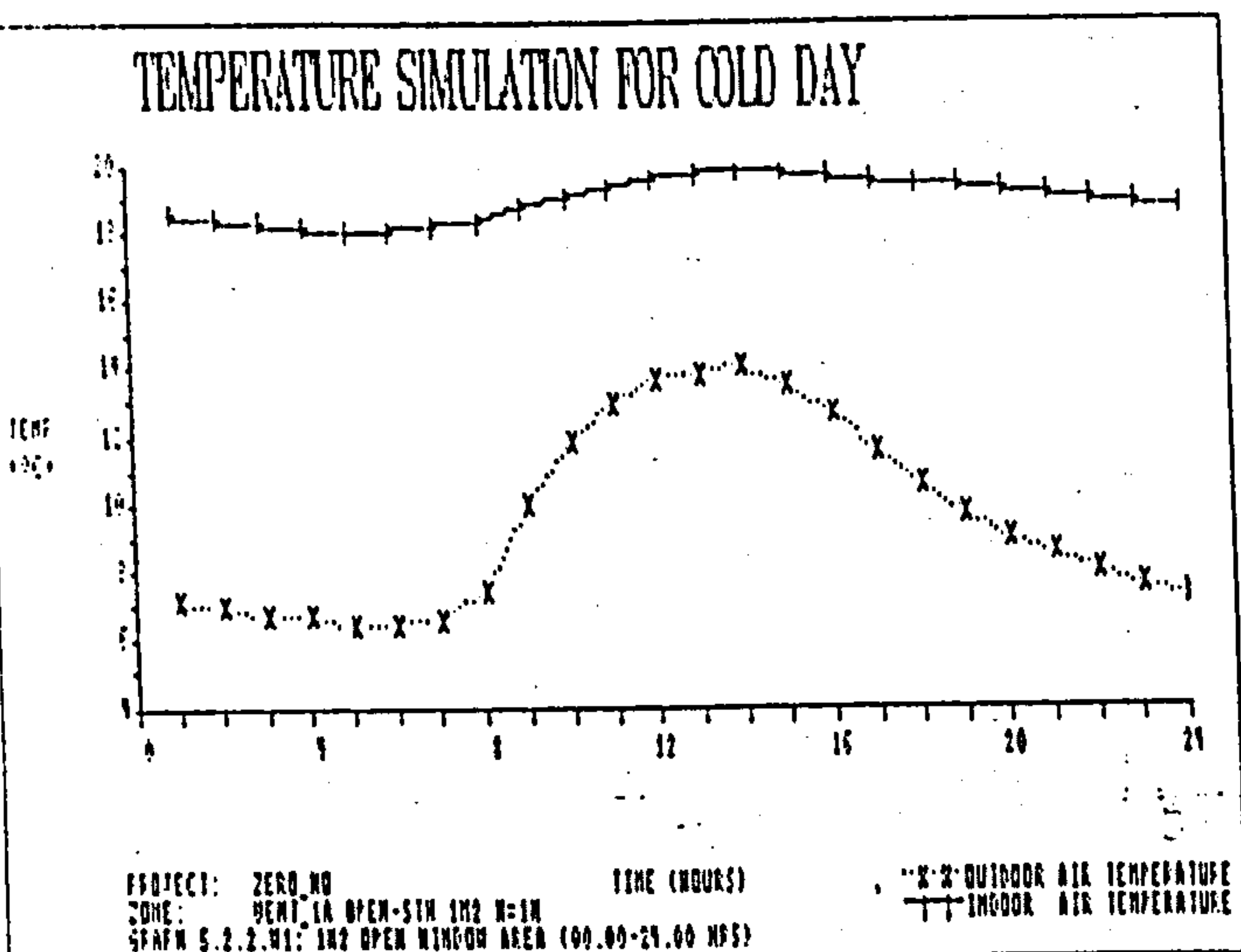
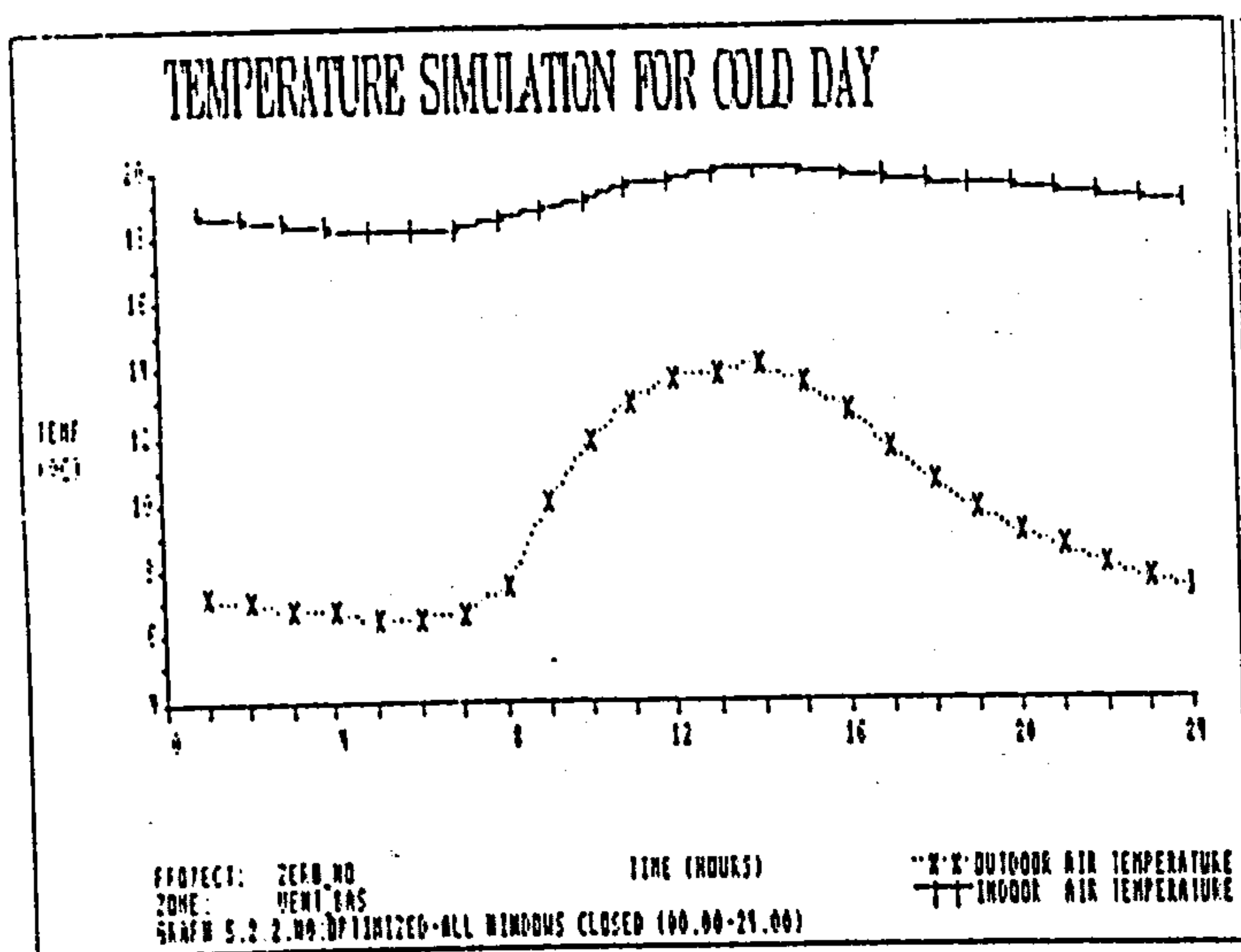


PROJECT: ZERO NO  
ZONE: VENT W4 S 10-7.5H2 .2-5H  
GRAPH 5.2.2.2.2: ALL WINDOWS OPEN 06.00-22.00 HOURS

TIME (HOURS)

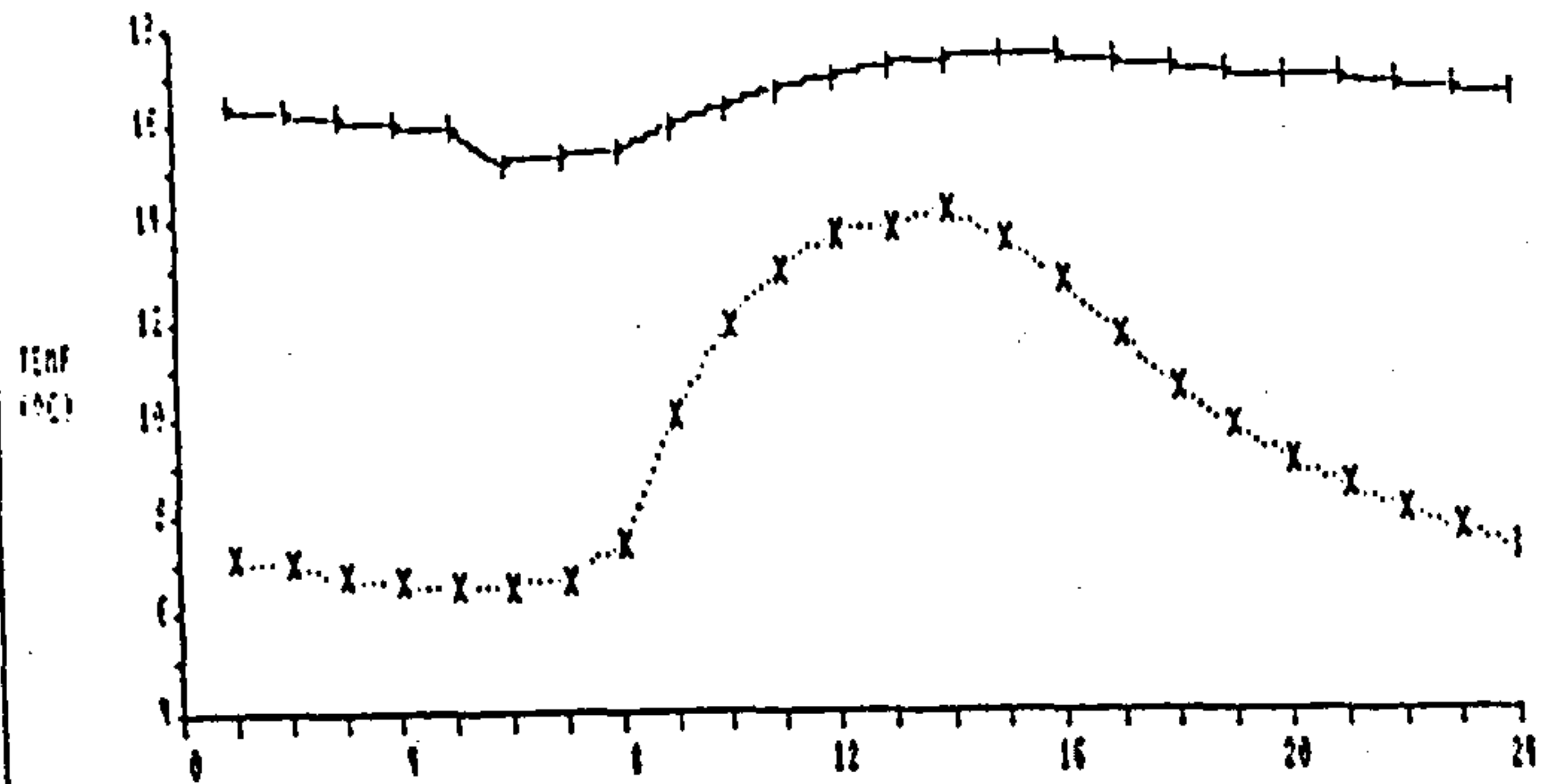
--X-- OUTDOOR AIR TEMPERATURE  
+ INDOOR AIR TEMPERATURE







### TEMPERATURE SIMULATION FOR COLD DAY

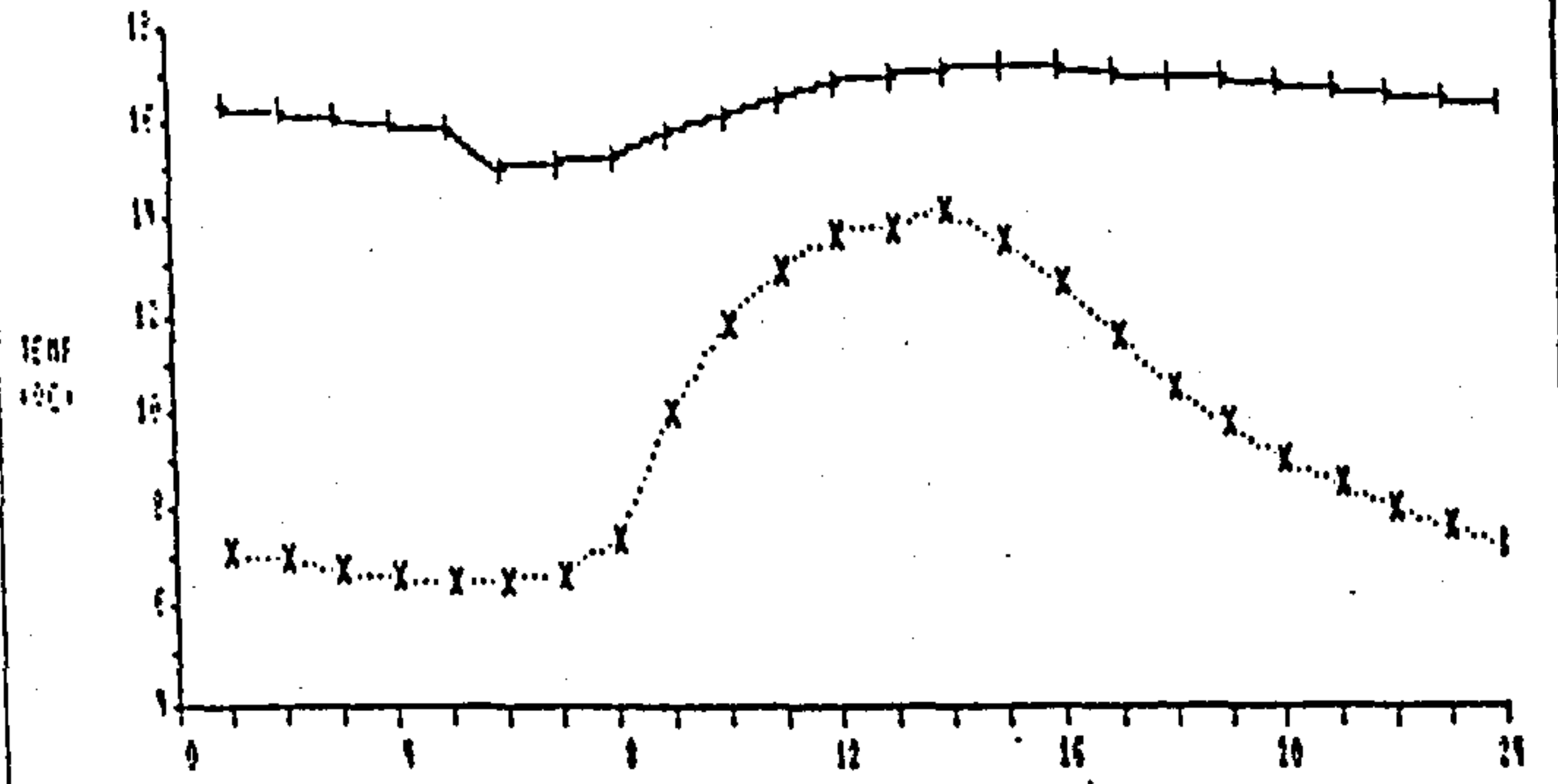


PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

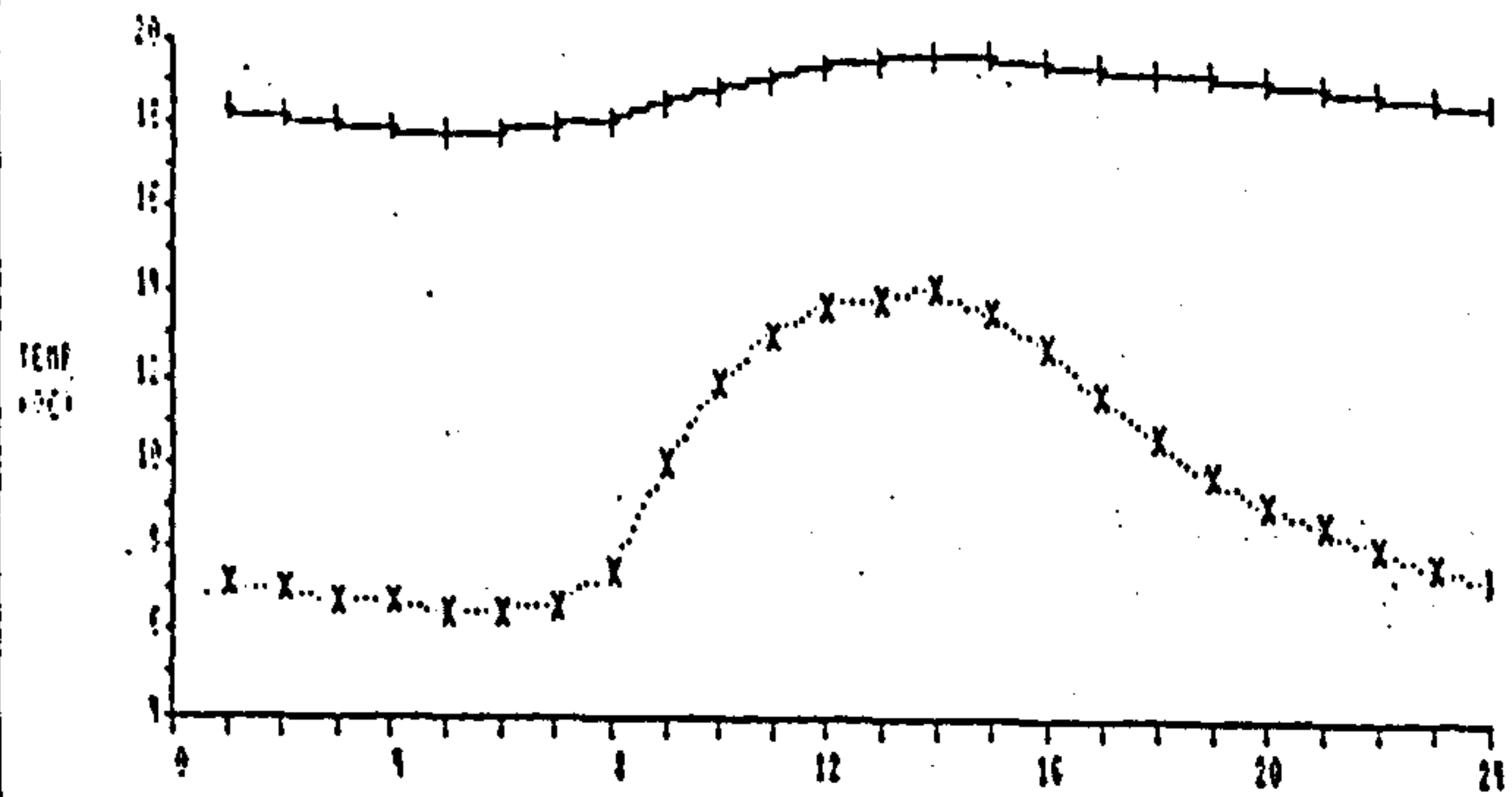


PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

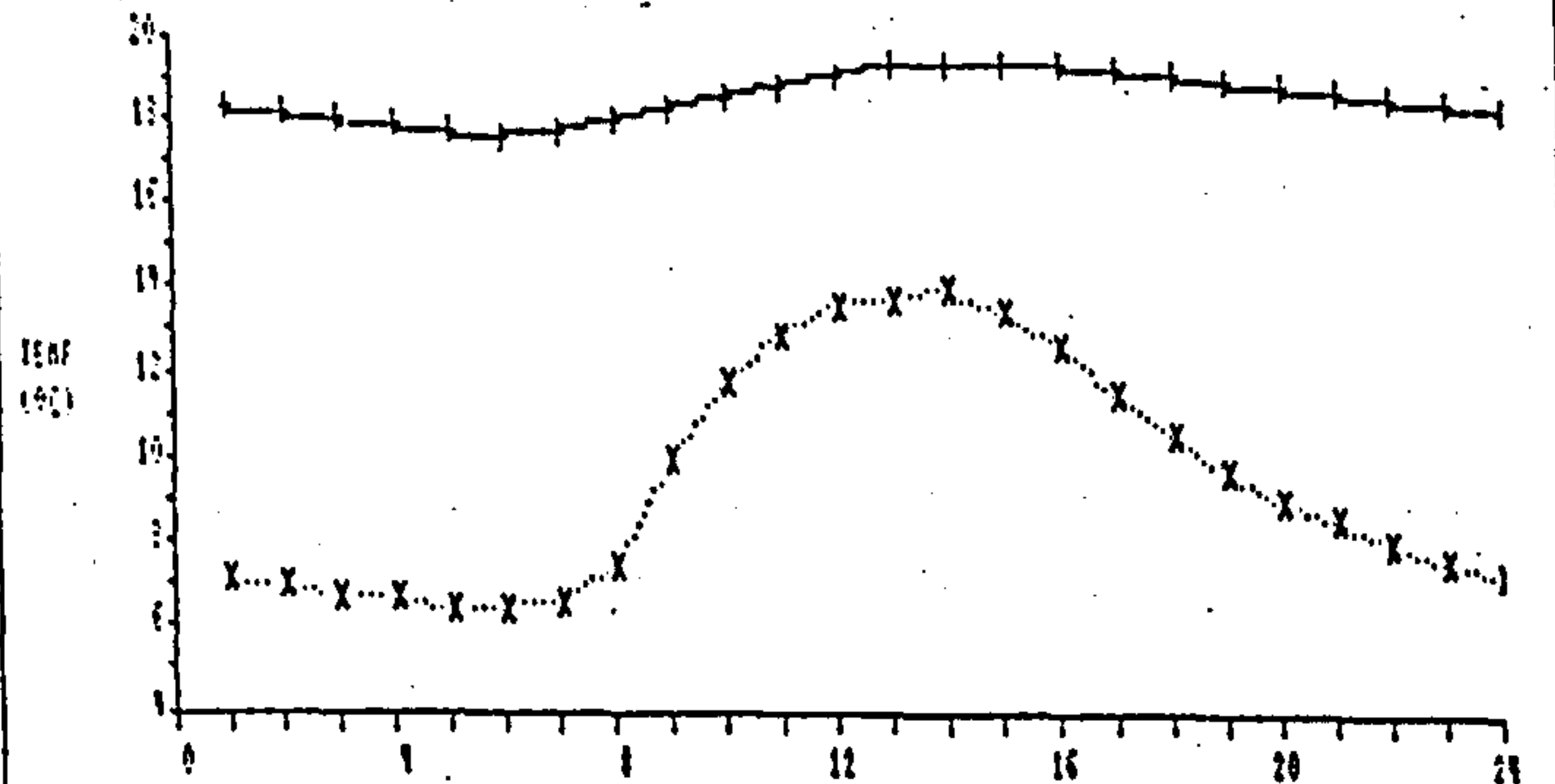


PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

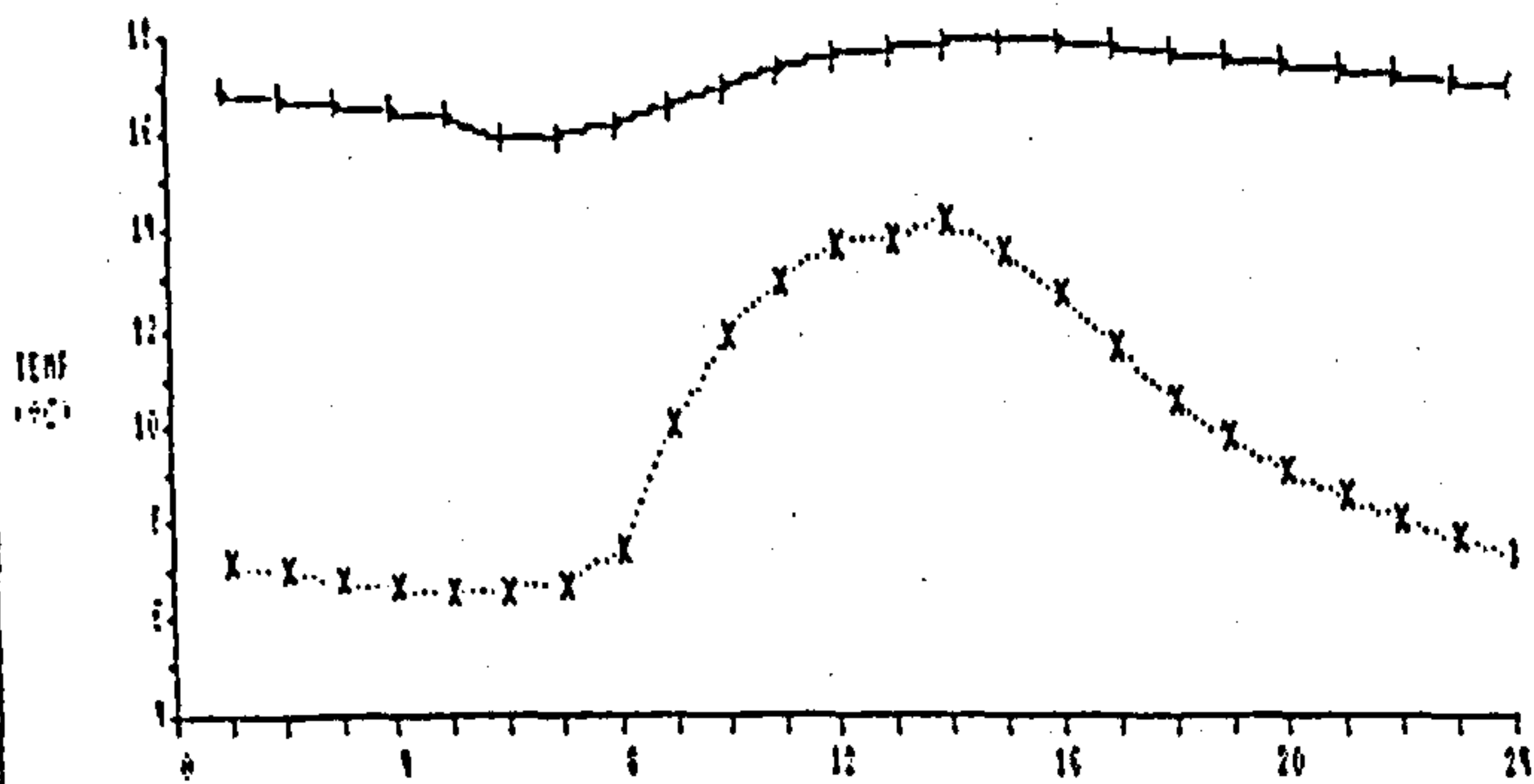


PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

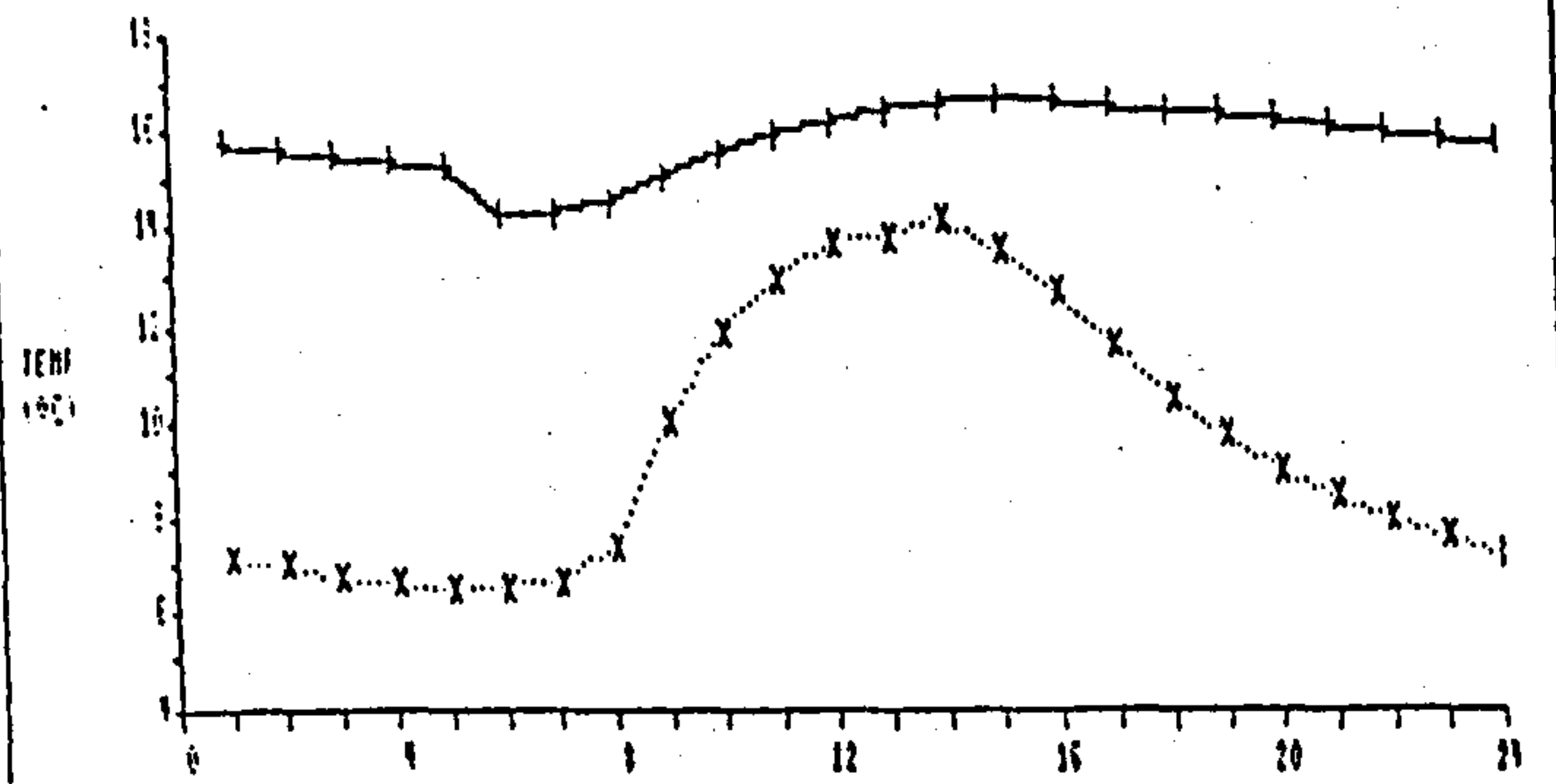


PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY



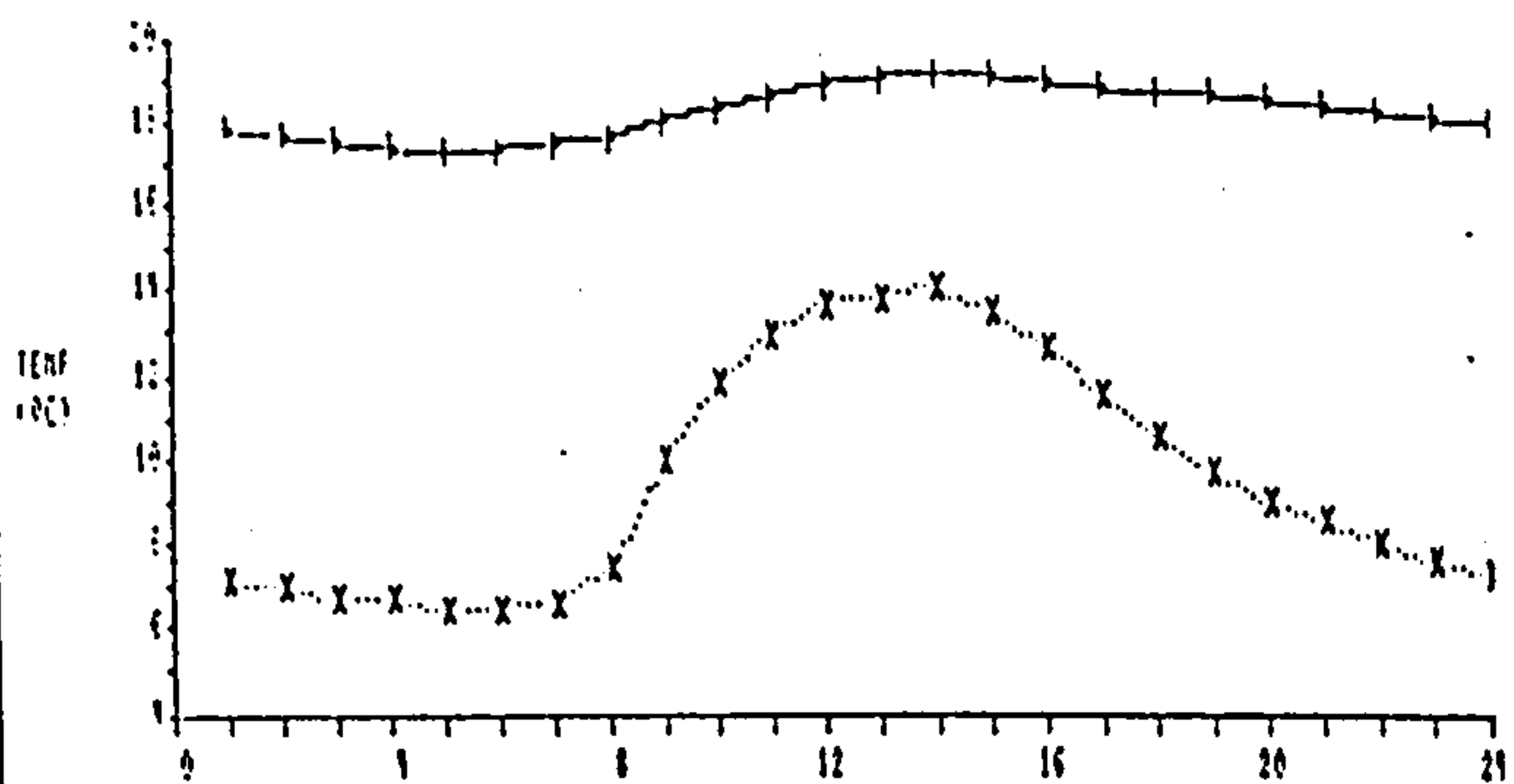
PROJECT: ZERO HQ  
ZONE: VENT W1 S-N 1-1.5M2 1-6M  
GRAPH S.2.2.W1:1.5M2 OPEN 00.00-24.00 AT 1M 6M HEIGHT

TIME (HOURS)

--X-- OUTDOOR AIR TEMPERATURE  
---+--- INDOOR AIR TEMPERATURE

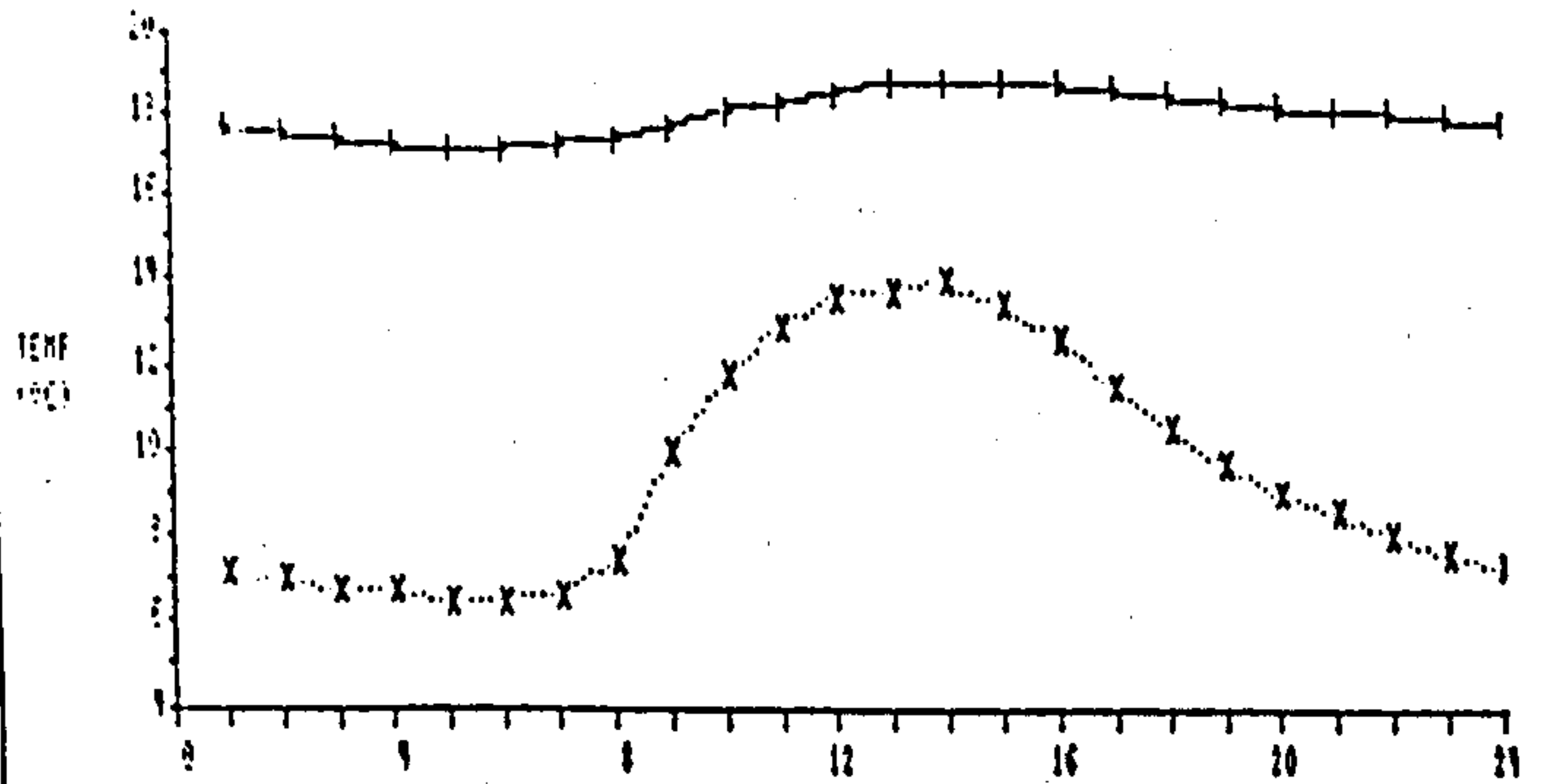


# TEMPERATURE SIMULATION FOR COLD DAY



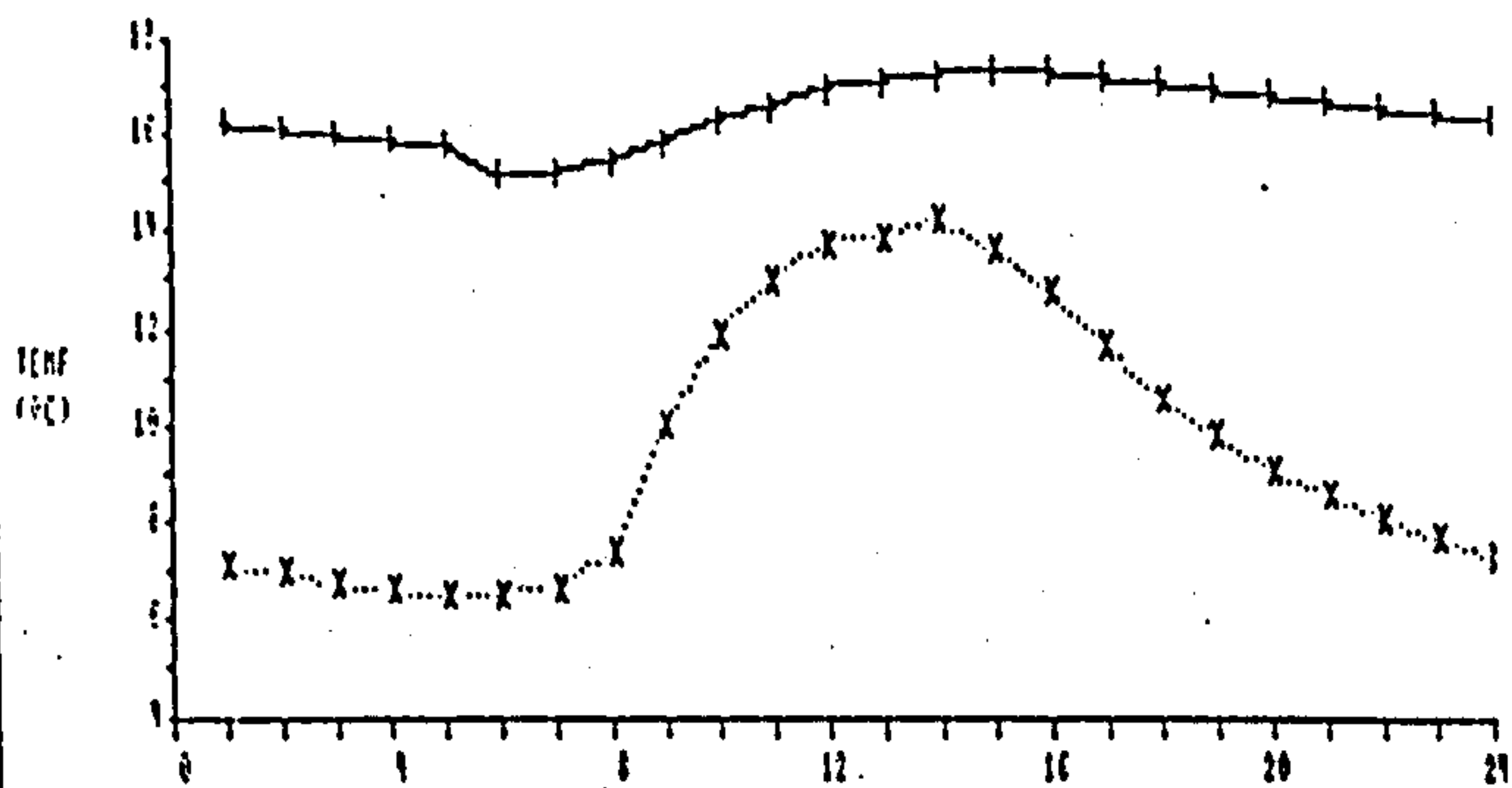
PROJECT: ZERO NO  
ZONE: VENT HAS STN 3.5M2 N=0.2M  
GRAPH 5.2.2.116: 3.5M2 OPEN 00.00-24.00 STN AT 0.2M HEIGHT

# TEMPERATURE SIMULATION FOR COLD DAY



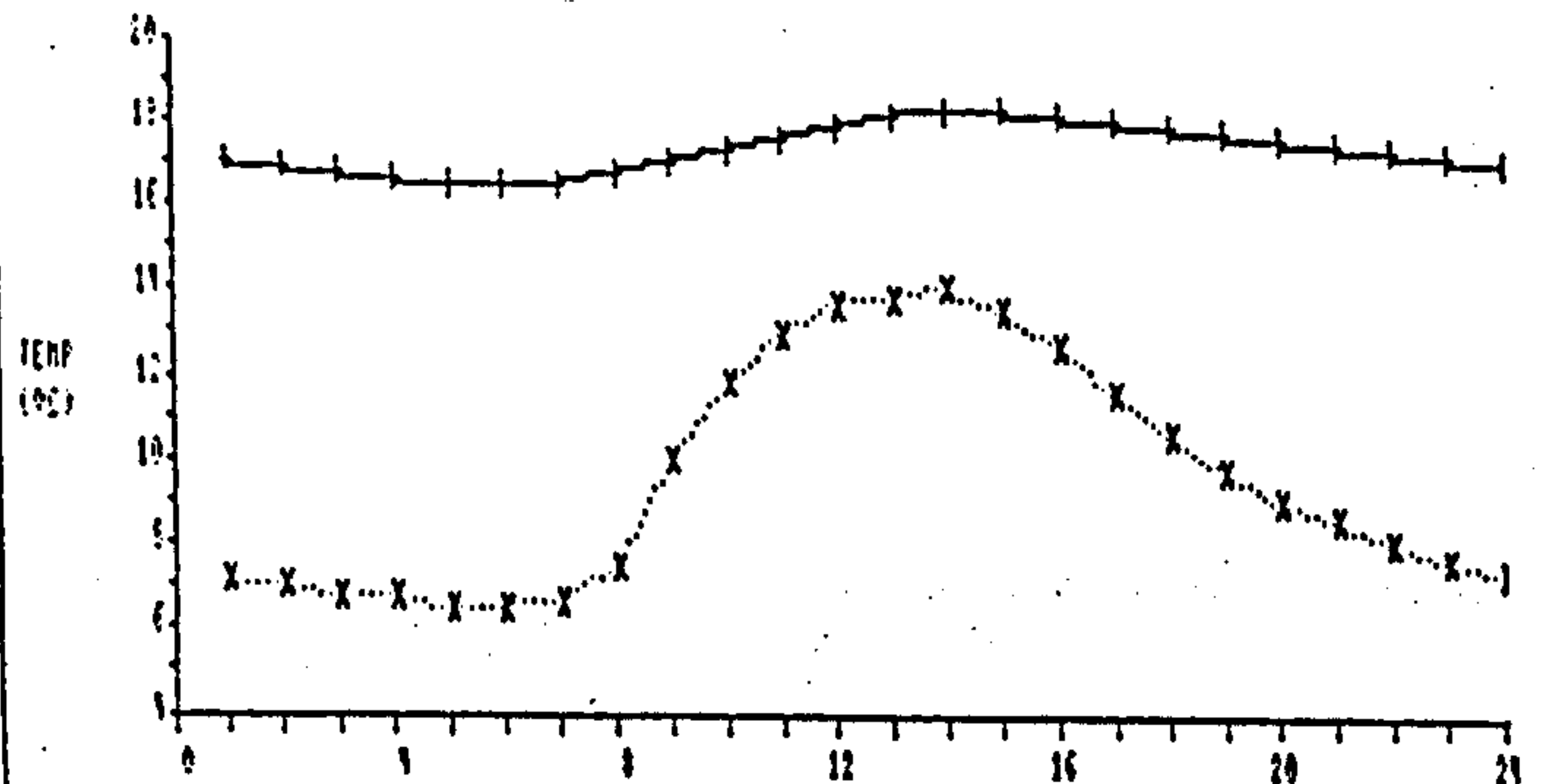
PROJECT: ZERO NO  
ZONE: VENT HAS NORTH 3.5M2 N=1M  
GRAPH 5.2.2.117: 3.5M2 OPEN 00.00-24.00 NORTH AT 1M HEIGHT

# TEMPERATURE SIMULATION FOR COLD DAY



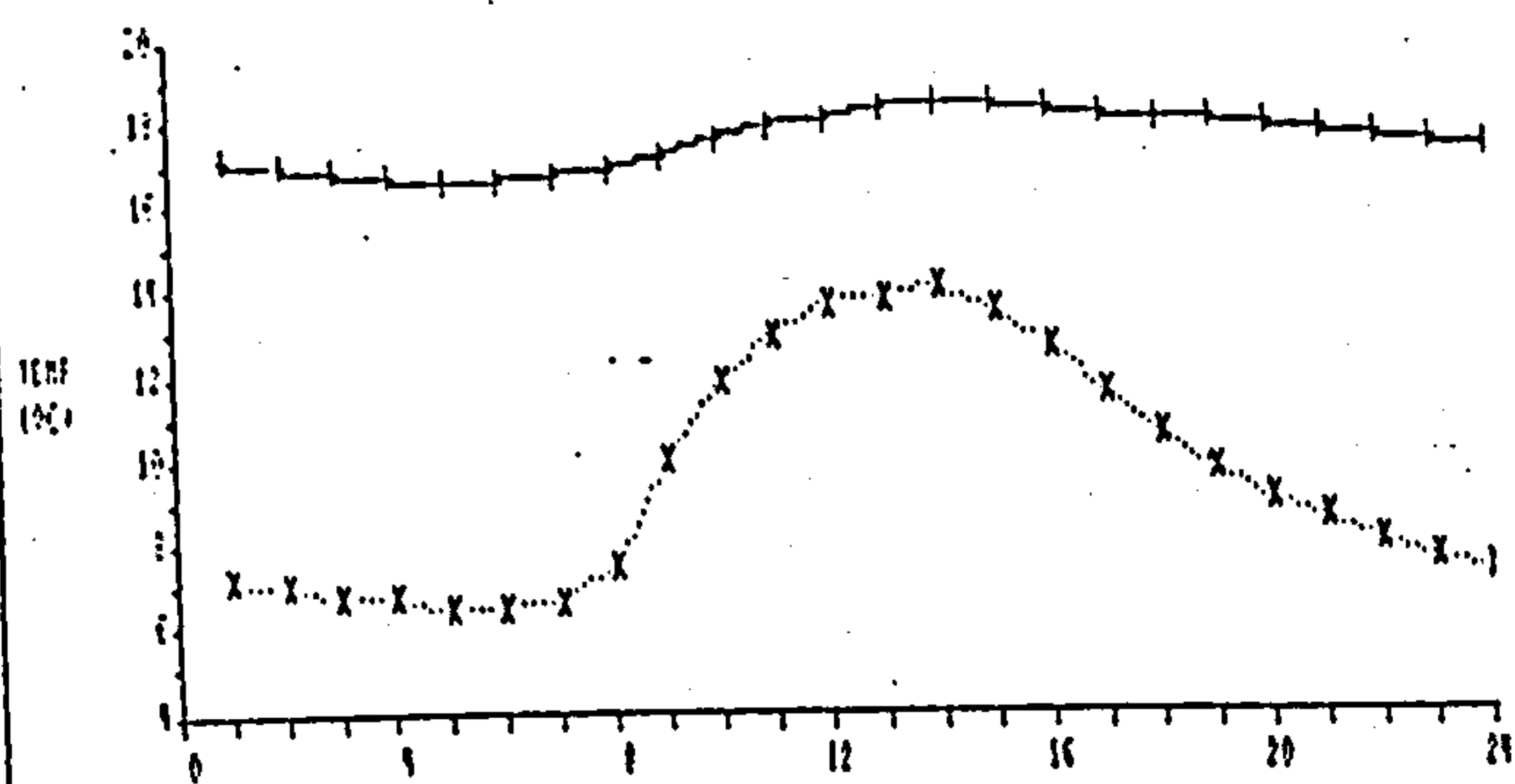
PROJECT: ZERO NO  
ZONE: VENT HAS N-S 3.5M2 N=1-2  
GRAPH 5.2.2.118: 3.5M2 OPEN 24 HRS STN AT 0.2M NORTH AT 1M

# TEMPERATURE SIMULATION FOR COLD DAY



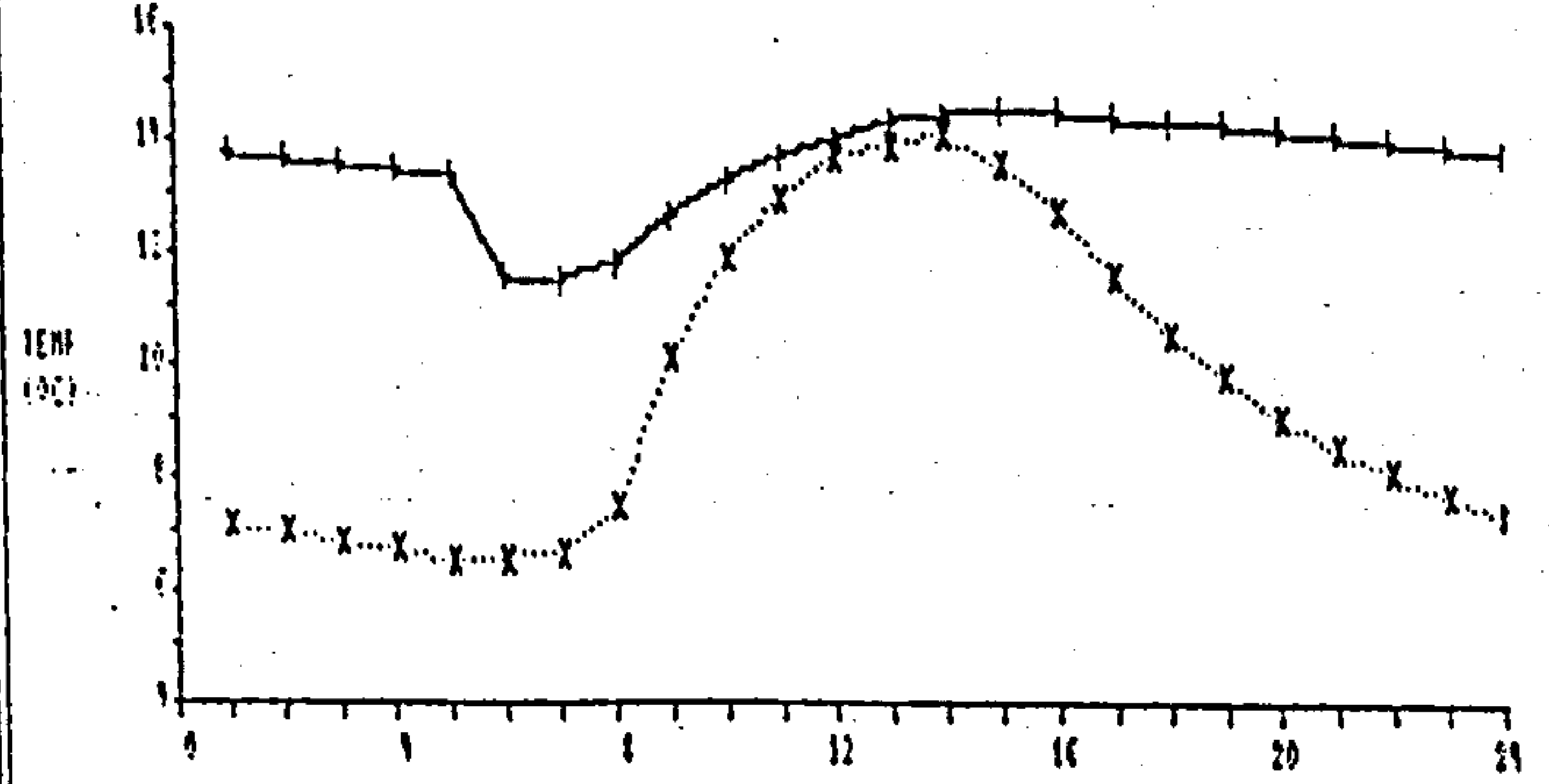
PROJECT: ZERO NO  
ZONE: VENT HAS STN 7.5M2 N=0.2M  
GRAPH 5.2.2.119: 7.5M2 OPEN 24 HRS STN AT 0.2M HEIGHT

# TEMPERATURE SIMULATION FOR COLD DAY



PROJECT: ZERO NO  
ZONE: VENT HAS STN 7.5M2 N=0.2M  
GRAPH 5.2.2.120: 7.5M2 24 HRS NORTH AT 0.2M HEIGHT

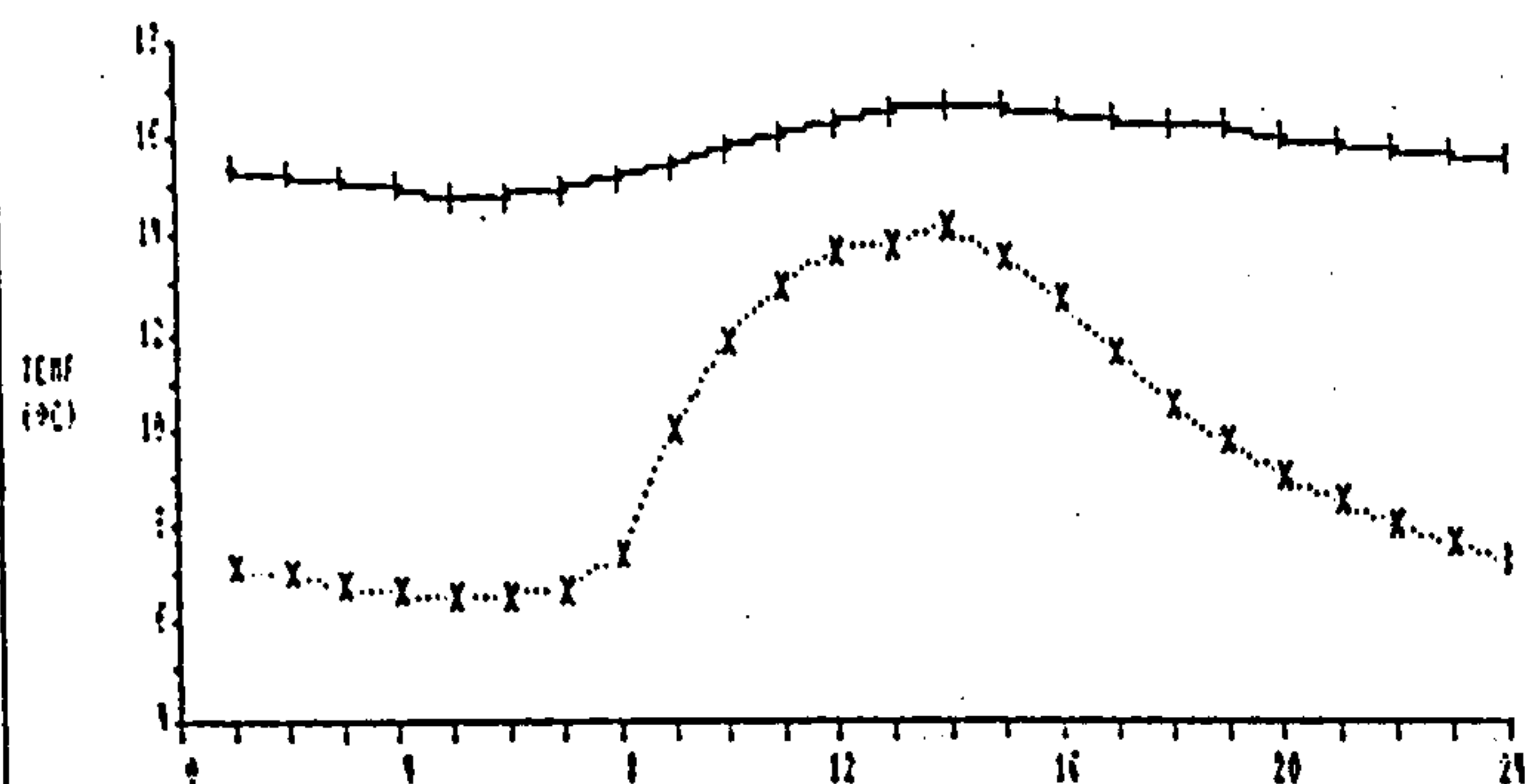
# TEMPERATURE SIMULATION FOR COLD DAY



PROJECT: ZERO NO  
ZONE: VENT HAS N-S 5-4M2 N=1-5M  
GRAPH 5.2.2.121: 7.5M2 OPEN NORTH 24HRS AT 1M & 5M HEIGHT



### TEMPERATURE SIMULATION FOR COLD DAY

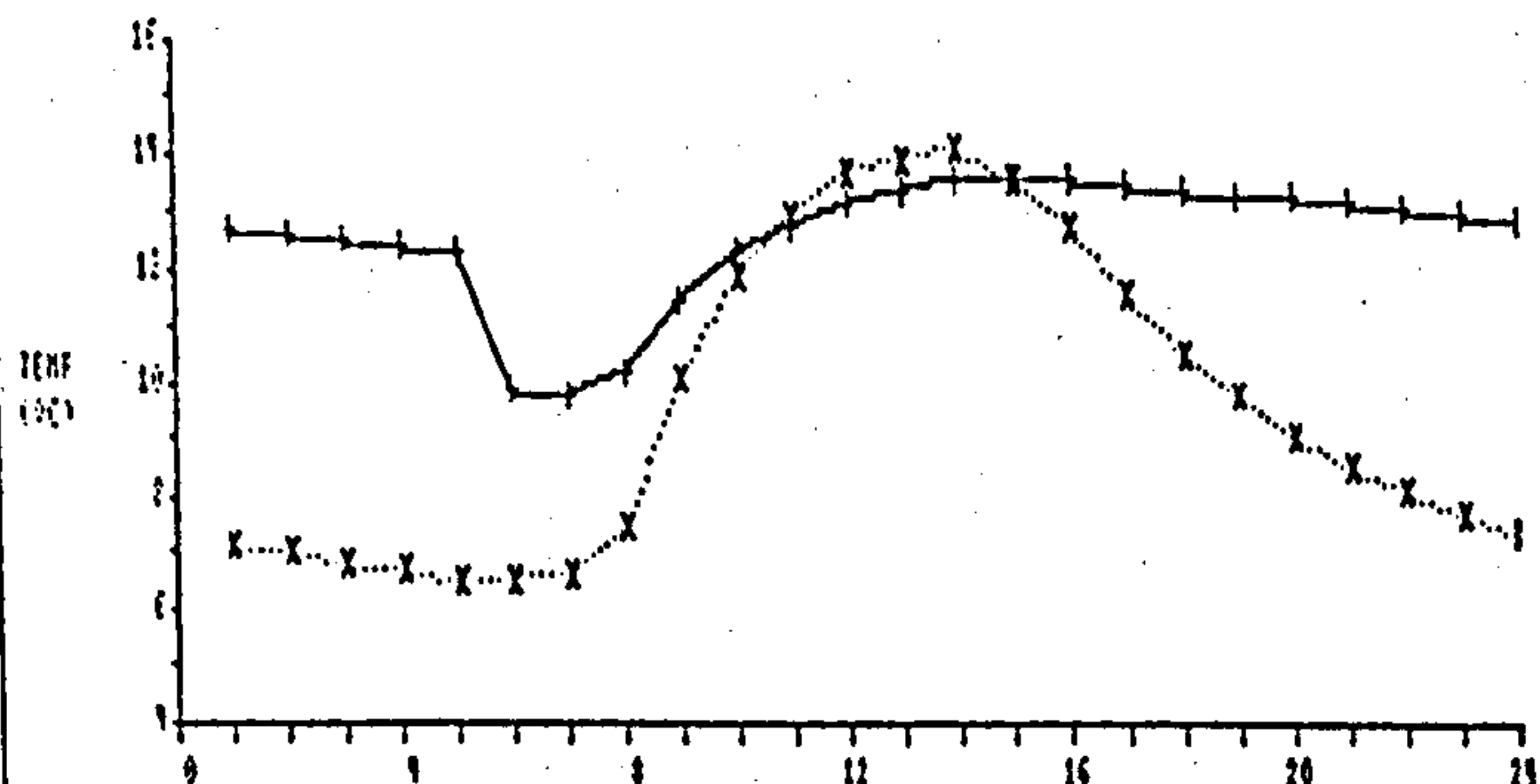


PROJECT: ZERO NO  
 ZONE: VENT HAD S 10-7.5M2 .2-SH  
 GRAPH S.2.2.22:17.5 M2 OPEN SOUTH AT 0.2M 00.00-24.00HRS

TIME (HOURS)

--X--X-- OUTDOOR AIR TEMPERATURE  
 +---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

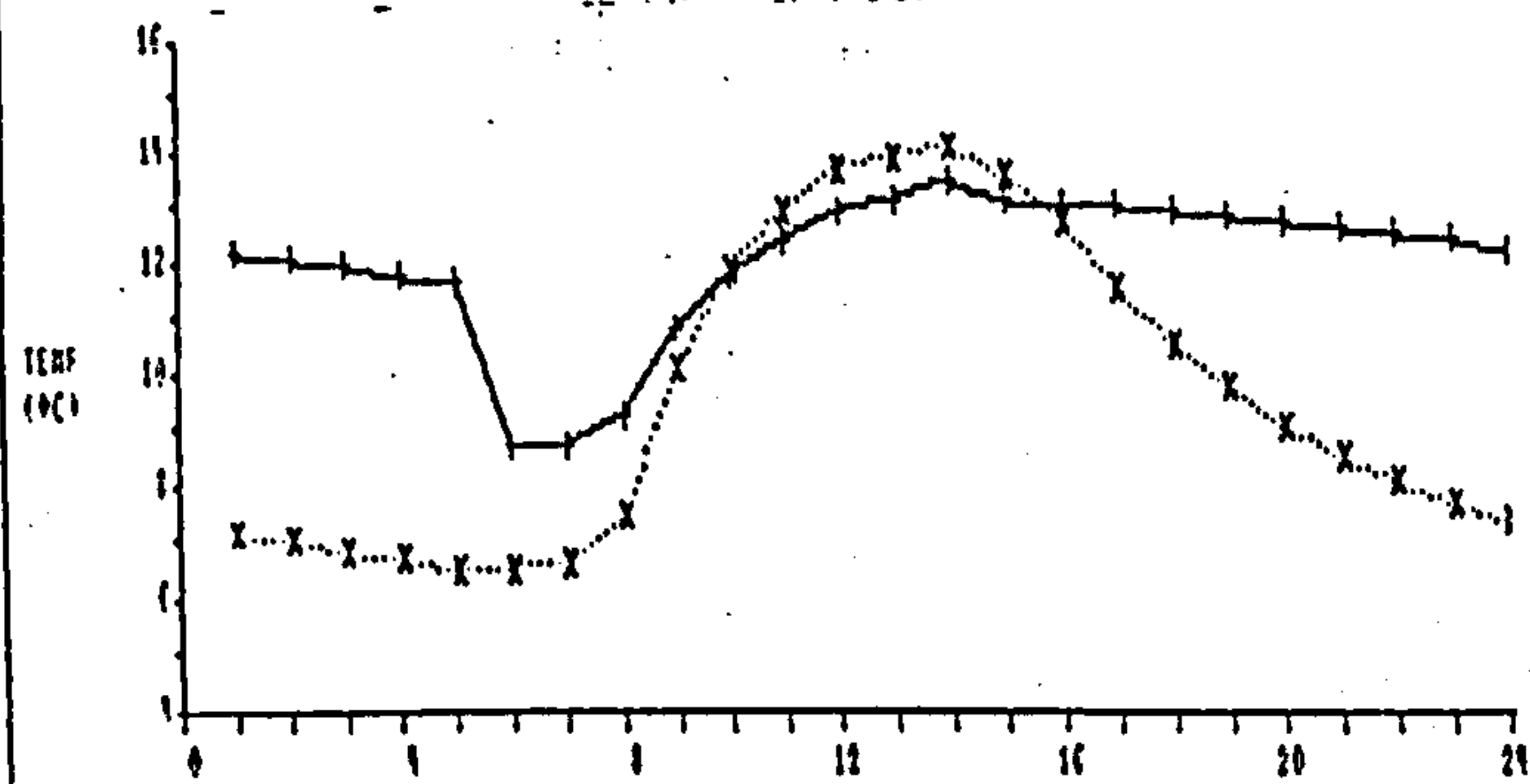


PROJECT: ZERO NO  
 ZONE: VENT HAD S 10-7.5M2 .2-SH  
 GRAPH S.2.2.23:17.5M2 OPEN 24HRS SOUTH AT .2 & 5M HEIGHT

TIME (HOURS)

--X--X-- OUTDOOR AIR TEMPERATURE  
 +---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY

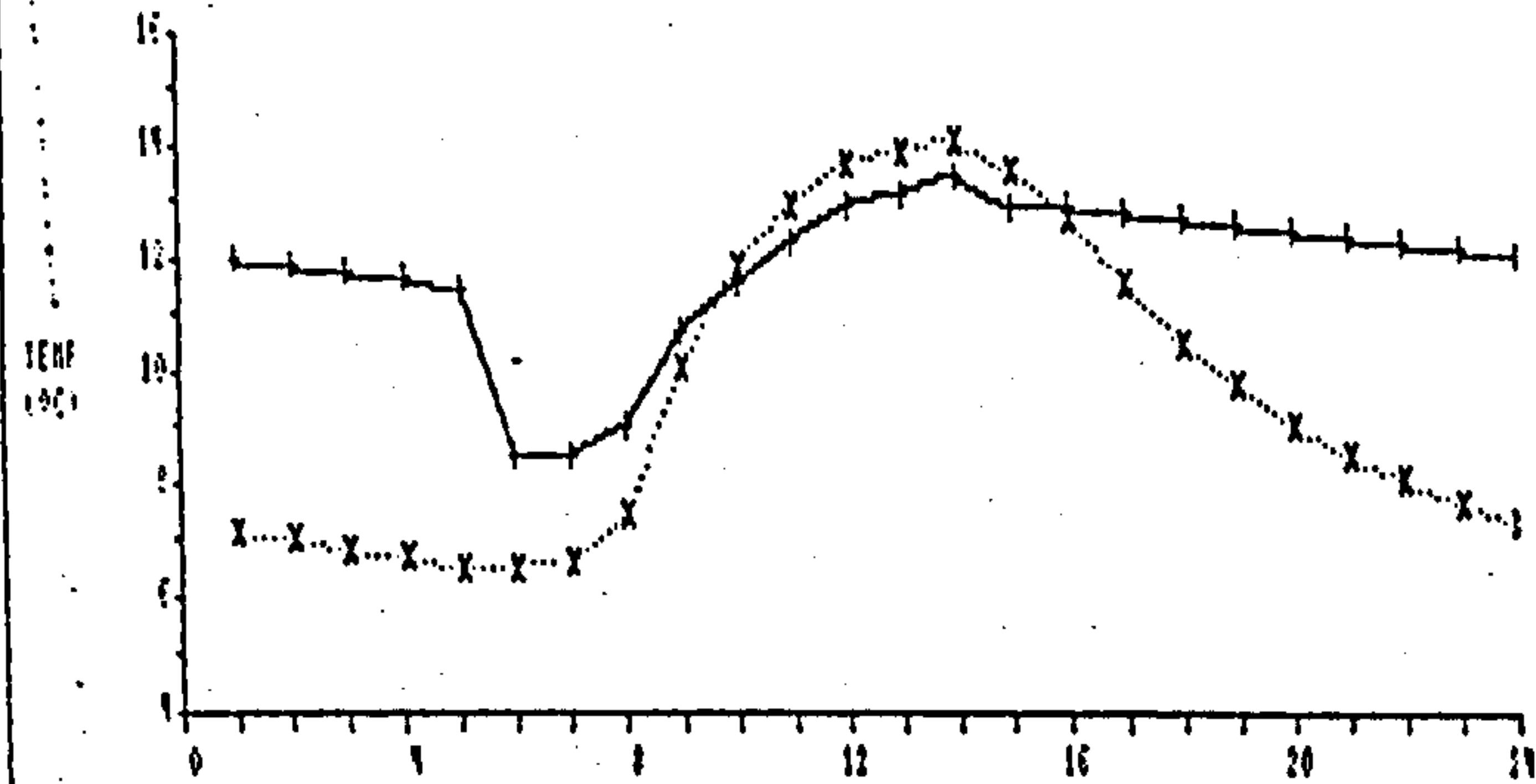


PROJECT: ZERO NO  
 ZONE: VENT HAD S 10-10M2 .2-SH  
 GRAPH S.2.2.24:35M2 OPEN AREA 00.00-24.00 AT 0.2M 0.0M H

TIME (HOURS)

--X--X-- OUTDOOR AIR TEMPERATURE  
 +---+--- INDOOR AIR TEMPERATURE

### TEMPERATURE SIMULATION FOR COLD DAY



PROJECT: ZERO NO  
 ZONE: VENT HAD ALL WINDOWS OPEN  
 GRAPH S.2.2.25: ALL WINDOWS OPEN 00.00-24.00 HRS

TIME (HOURS)

--X--X-- OUTDOOR AIR TEMPERATURE  
 +---+--- INDOOR AIR TEMPERATURE



## **APPENDIX 5.3.0**

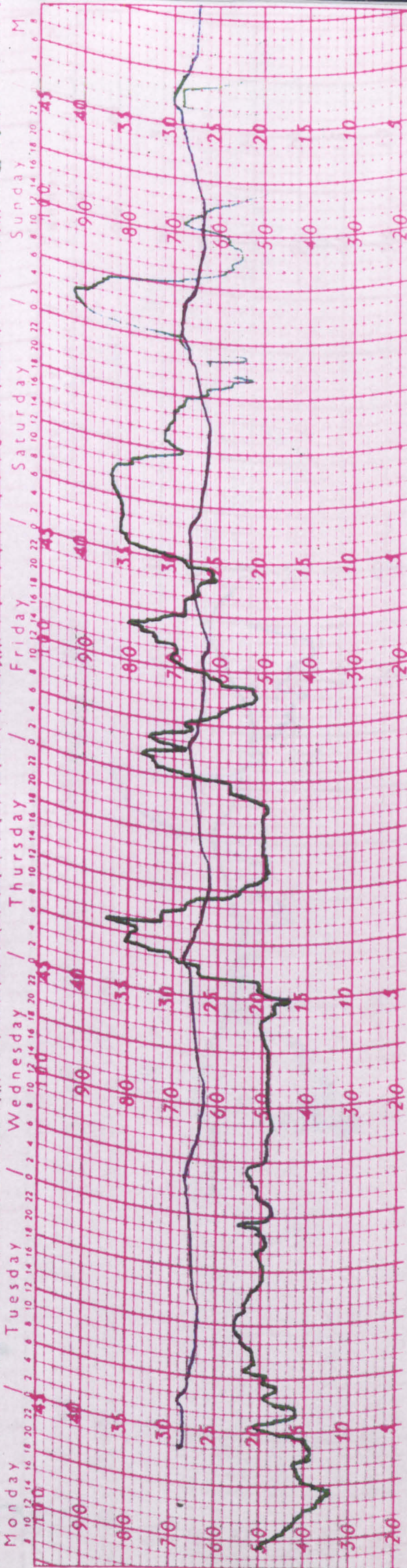
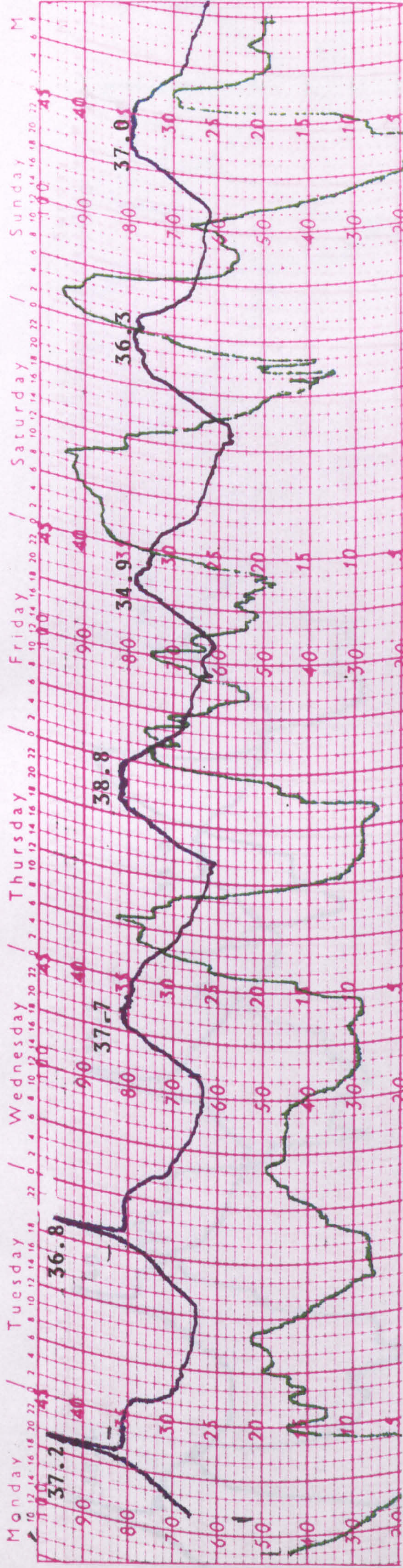
### **FIELD STUDY - RECORDINGS**

**TEMPERATURE AND HUMIDITY SUMMER 1993**  
**(July, August, September)**

#### **GRAPHS 5.3.1 - 5.3.9**

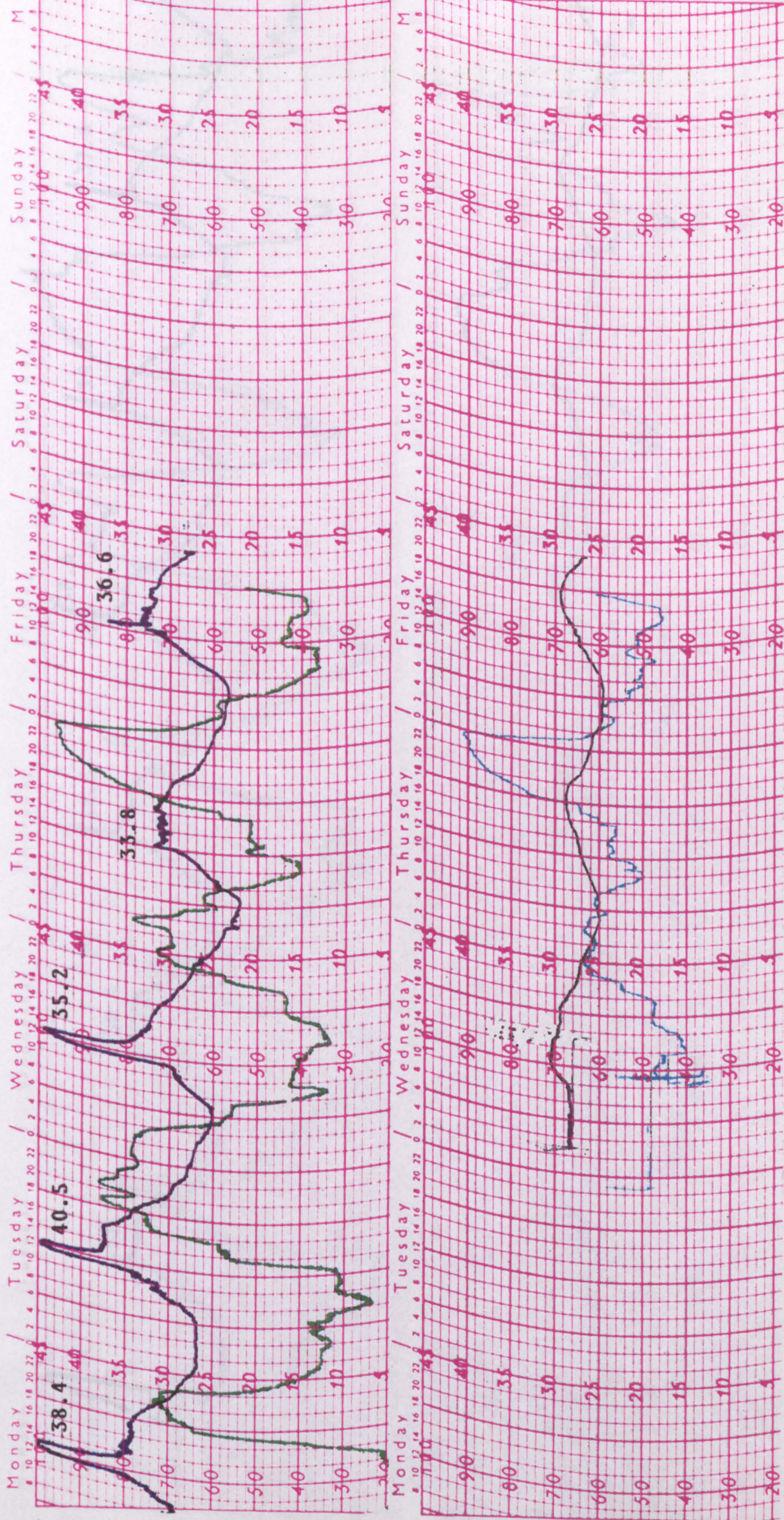
<b>TOP</b>	<b>- Recordings Externally</b>
<b>BOTTOM</b>	<b>- Recordings Internally</b>
<b>BLUE</b>	<b>- Temperature</b>
<b>GREEN</b>	<b>- Humidity</b>





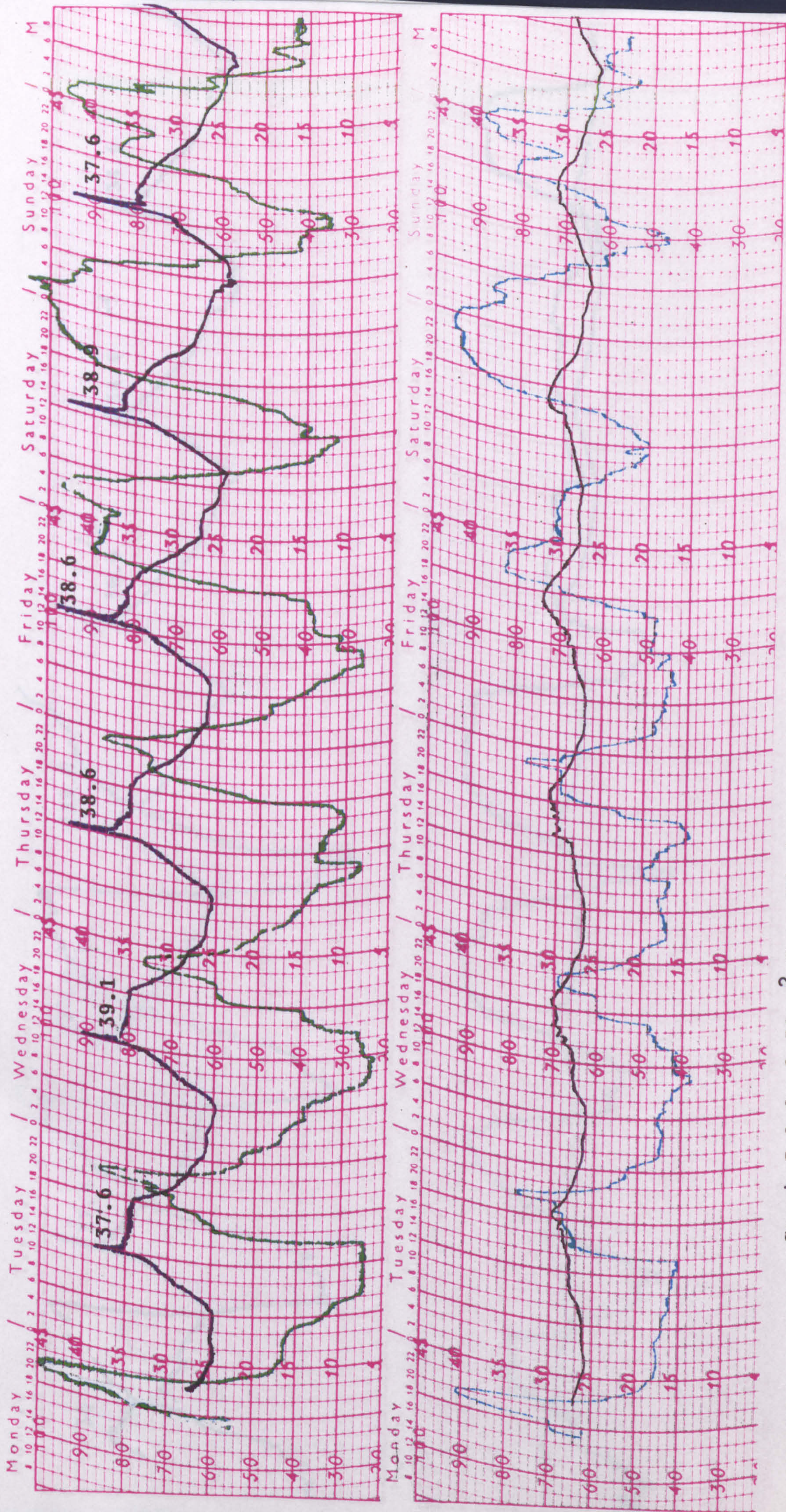
Graph 5.3.1: All Windows Open Between 20.00-07.00 Hours  
All Windows Closed Between 07.00-20.00 Hours  
T Externally 24.0-38.8 °C  
T Internally 26.0-29.0 °C





Graph 5.3.2: All Windows Open 24 Hours  
T Externally 22.0-40.5 °C  
T Internally 24.0-30.0 °C



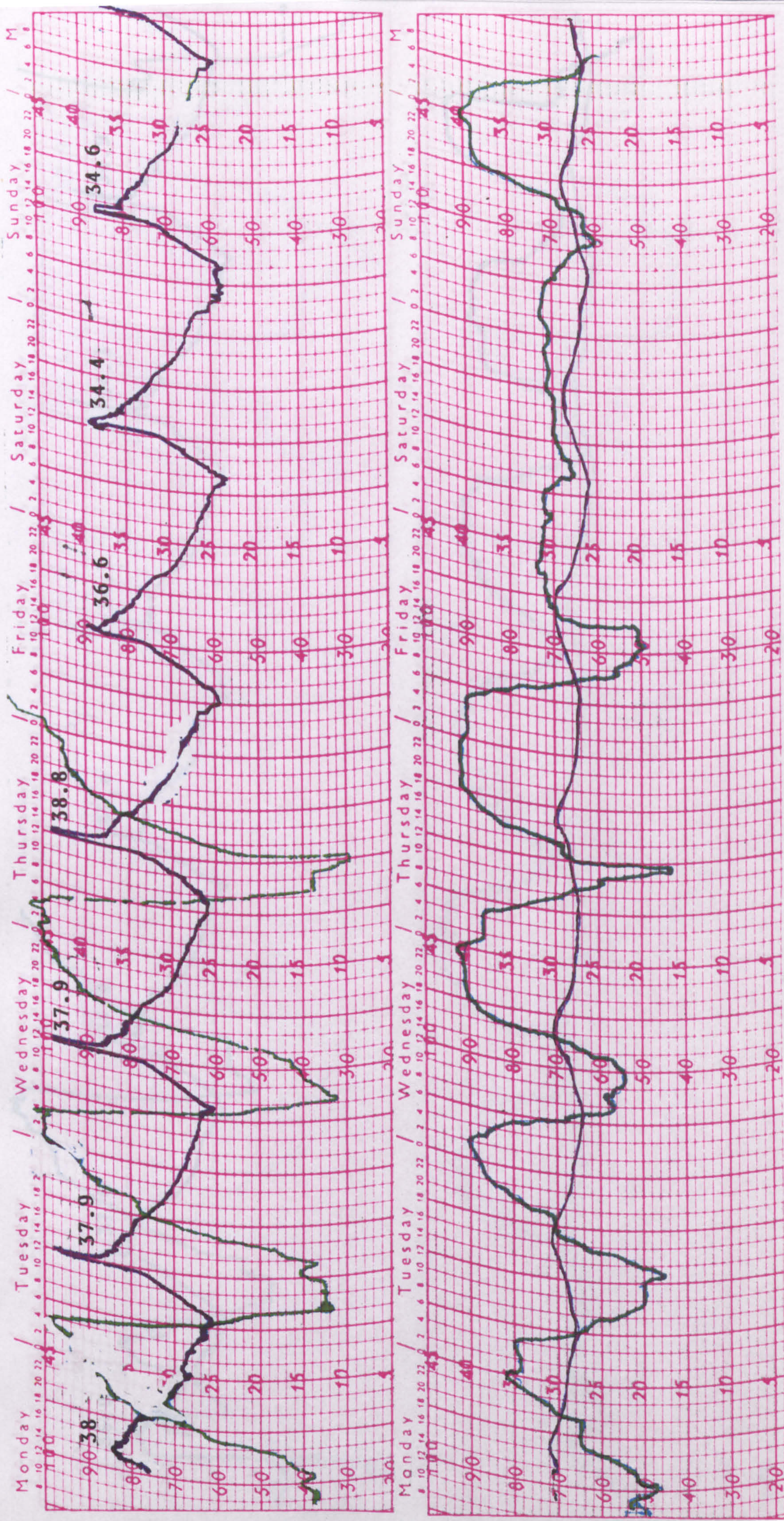


Graph 5.3.3: 3.50 m<sup>2</sup> Open Window 24 Hours

T Externally 24.0-39.1 °C

T Internally 26.0-32.0 °C



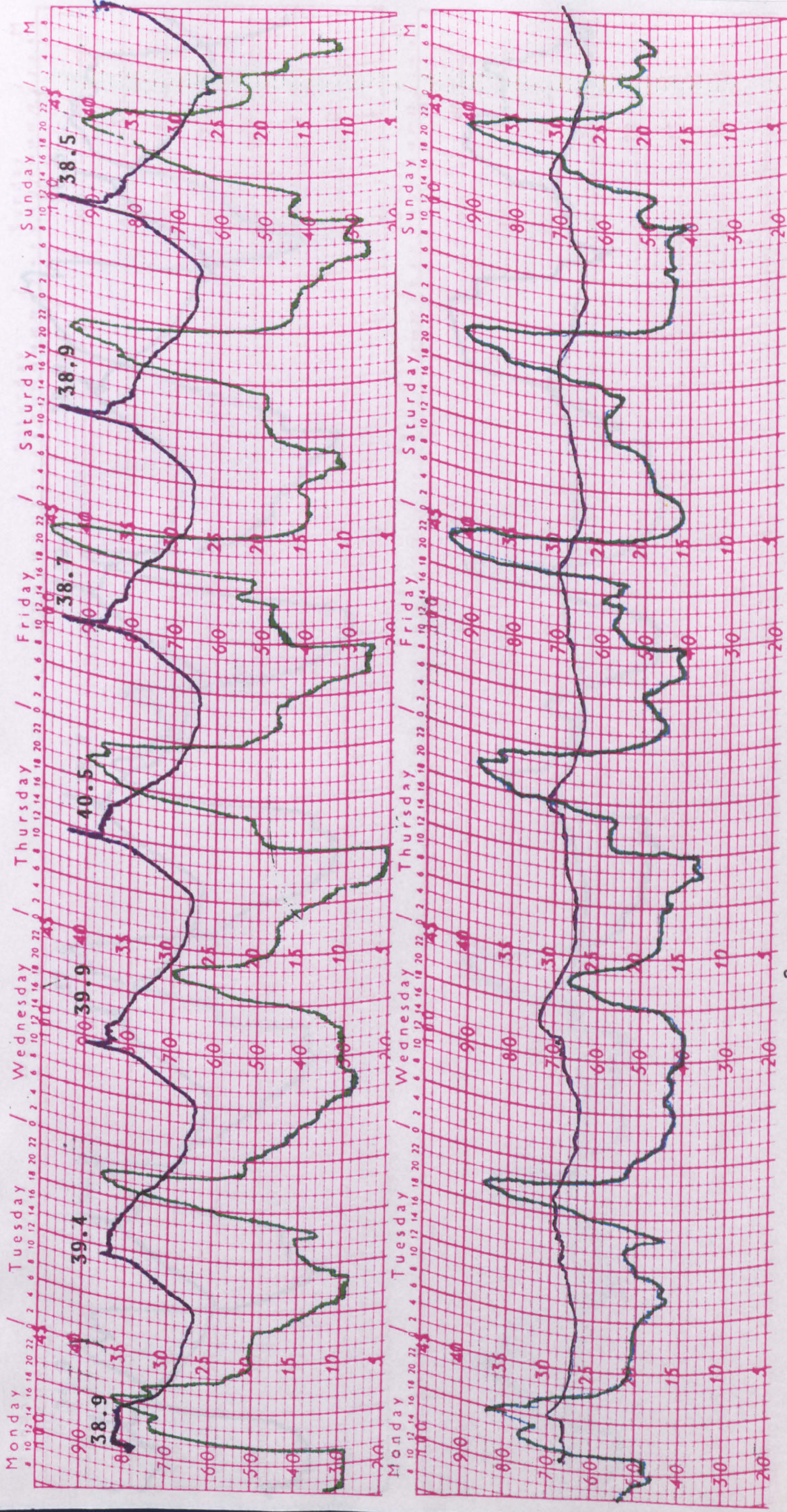


Graph 5.3.4: 3.50 m<sup>2</sup> Open Window Area 24 Hours

T Externally 23.0-38.8 °C

T Internally 26.0-31.0 °C



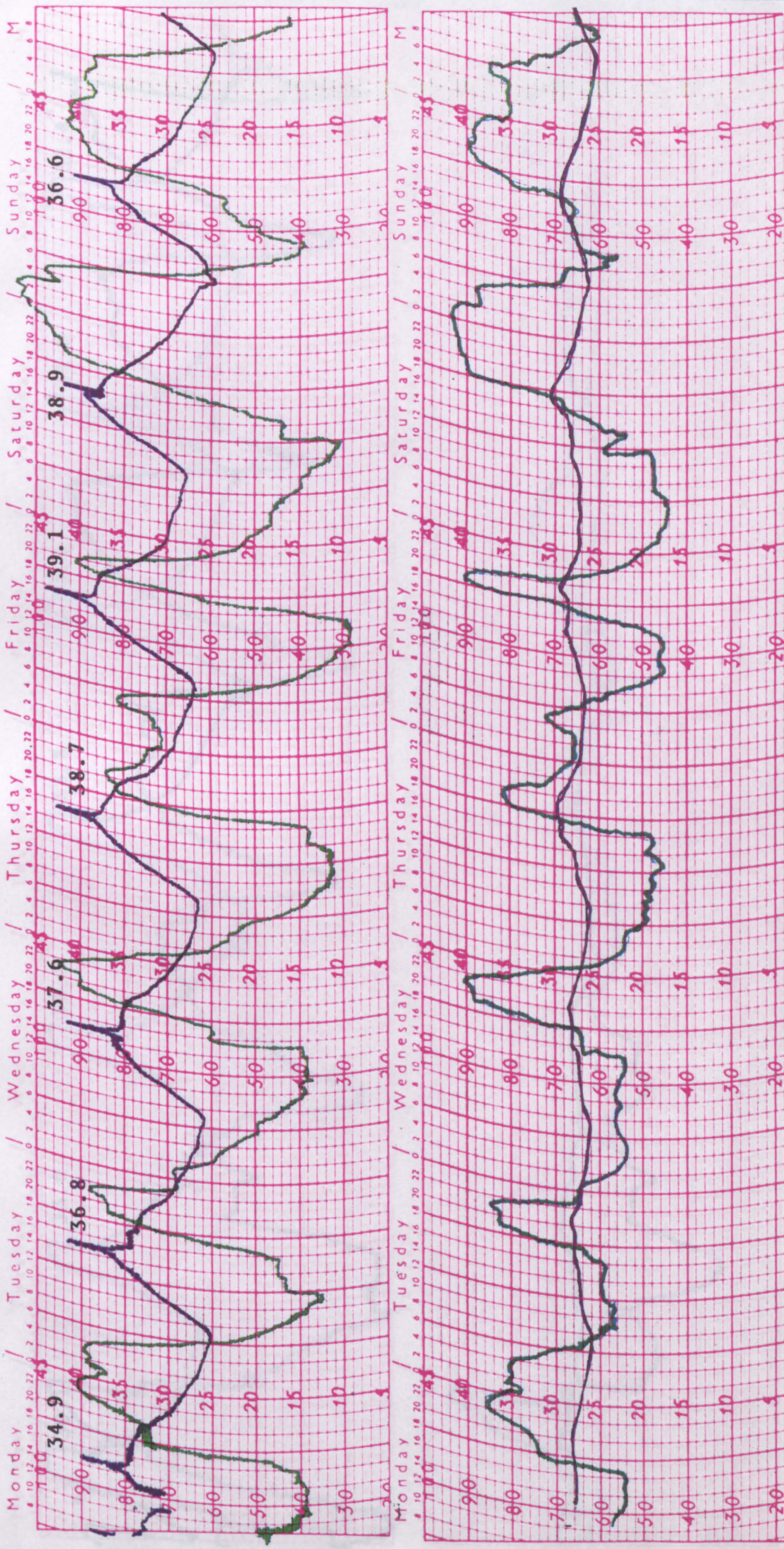


Graph 5.3.6: 2.00 m<sup>2</sup> Open Window 24 Hours

T Externally 25.0-40.5 °C

T Internally 27.0-32.0 °C



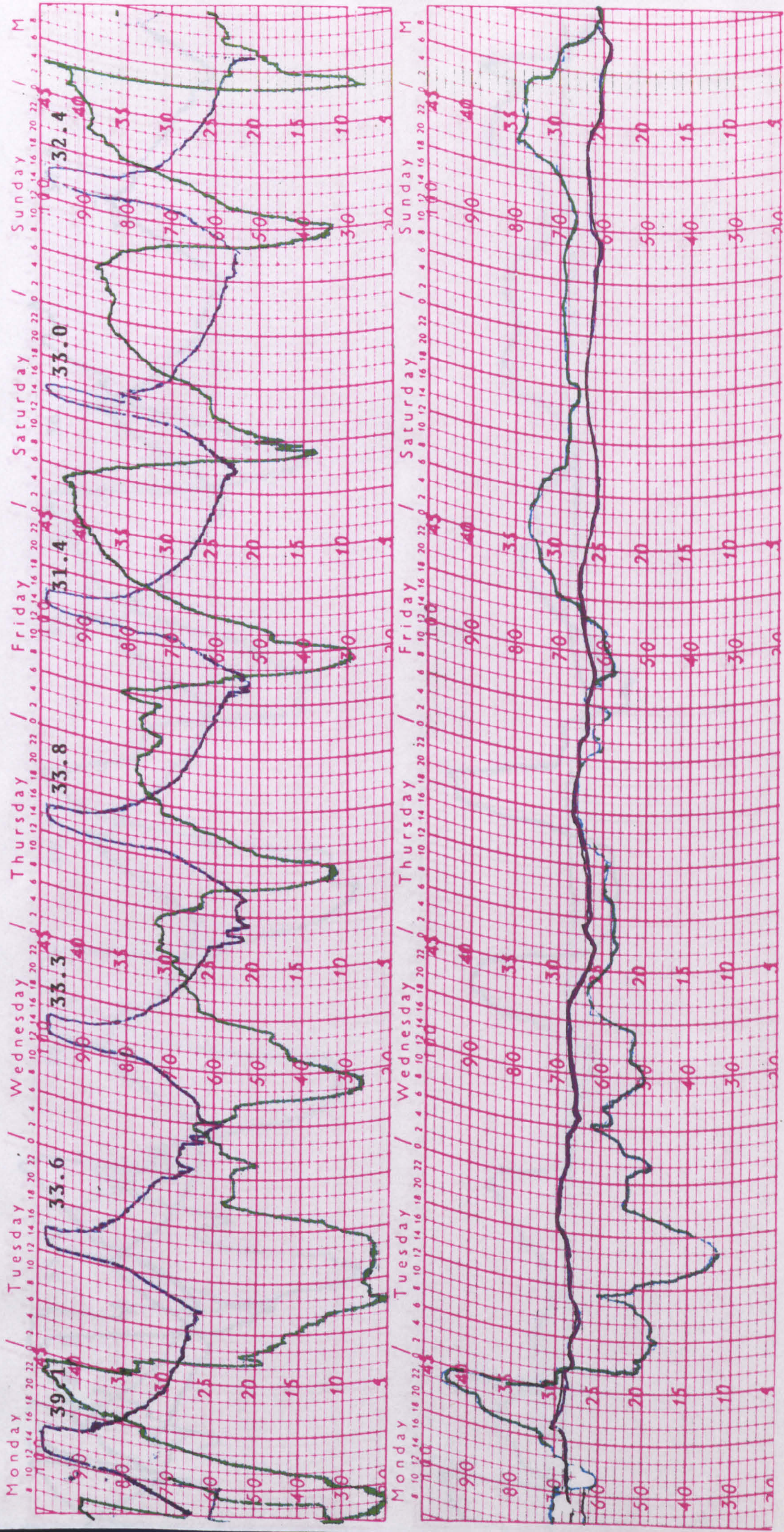


Graph 5.3.7: 1.50 m<sup>2</sup> Open Window Area 24 Hours

T Externally 24.5-39.1 °C

T Internally 25.5-30.5 °C



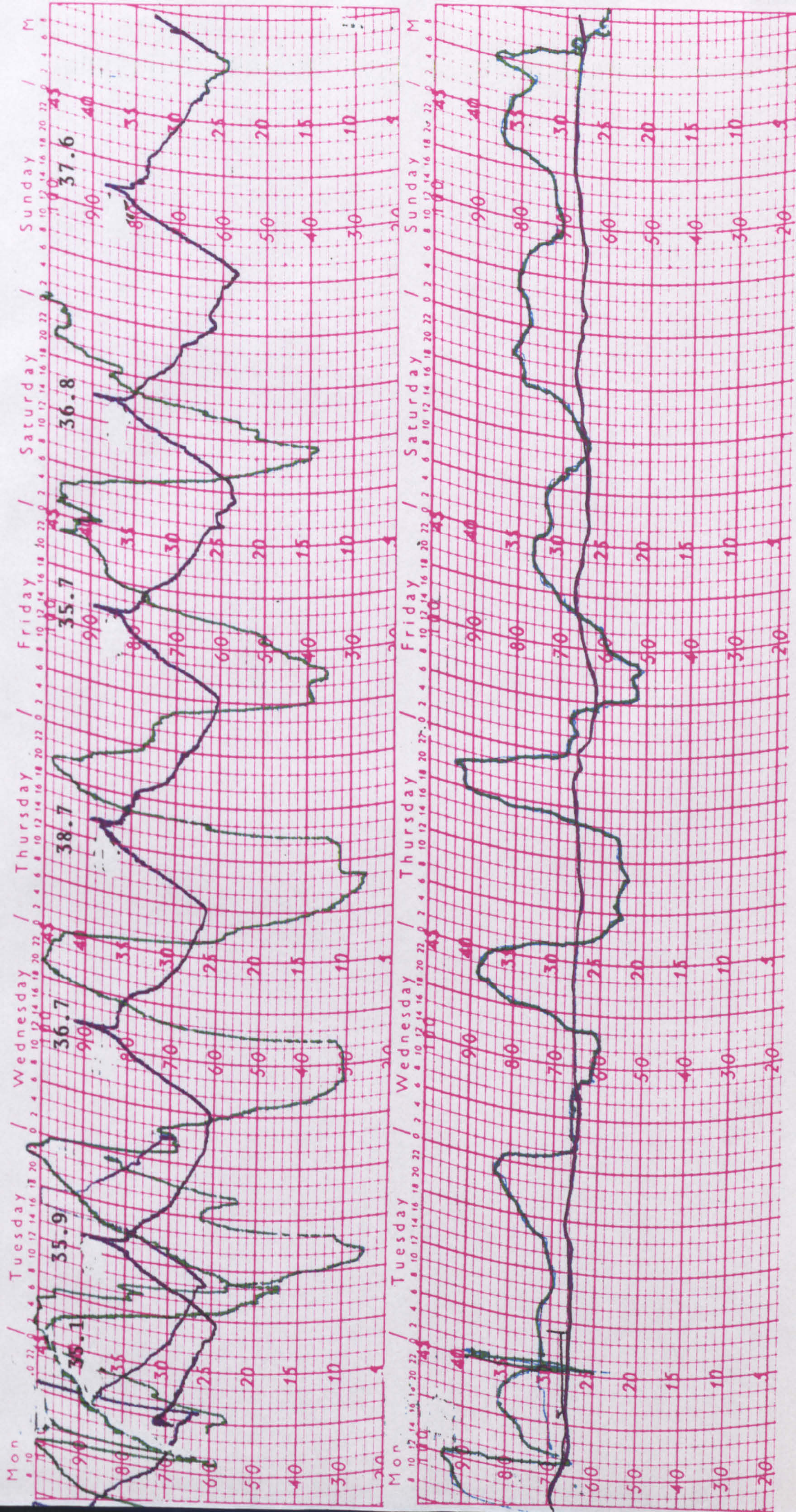


Graph 5.3.8: 2.00 m<sup>2</sup> Open Window Area Between 20.00-07.00 Hours

T Externally 21.0-42.0 °C

T Internally 24.0-30.0 °C





Graph 5.3.9: Ventilation Regulated by Inhabitants

T Externally 23.0-38.7 °C

T Internally 26.0-29.0 °C